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GENERAL ELECTRIC REVIEW

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August 1950

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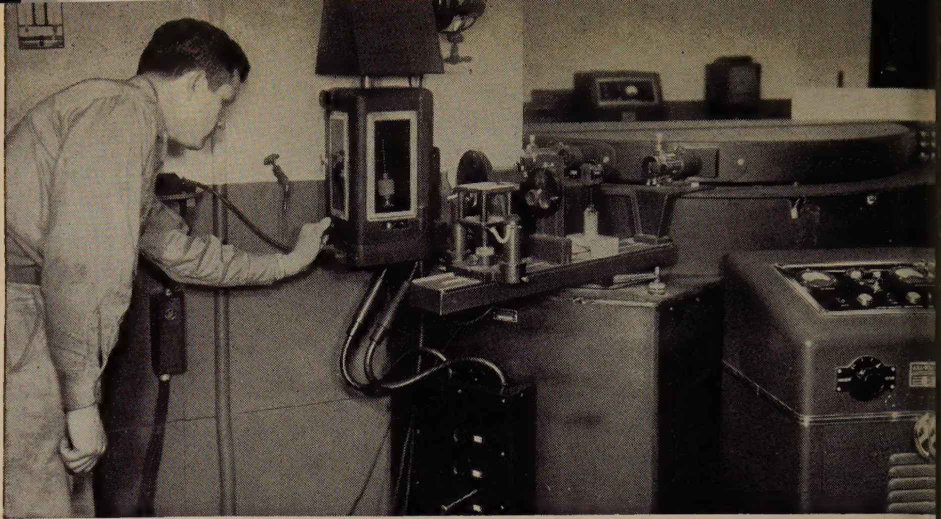

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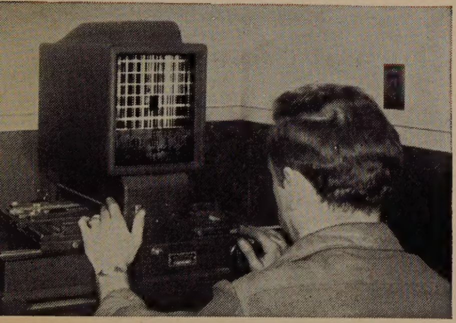

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GENERAL ELECTRIC Review

AUGUST 1950
Vol. 53, No. 8

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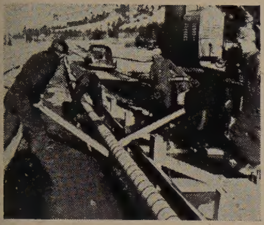

THE COVER

Photo: Electrical Constructors, Inc., and C. M. Elliott

The route chosen for transfer of electric power between generating plants on the eastern and western slopes of the Rocky Mountains in Colorado is via the 13½ miles of the Alva B. Adams Irrigation Tunnel. Half-mile sections of three 69,000-volt cables in a steel pipe were moved on a temporary wooden "railroad" between stock pile and tunnel mouth, to be hung from the tunnel ceiling just above the water level. The sections of pipe are joined by welding and are filled with nitrogen at 200-lb pressure. (*See p. 46.*)

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Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under Act of March 3, 1879. Published monthly by General Electric Company, 1 River Road, Schenectady 5, N. Y. Printed in U. S. A.

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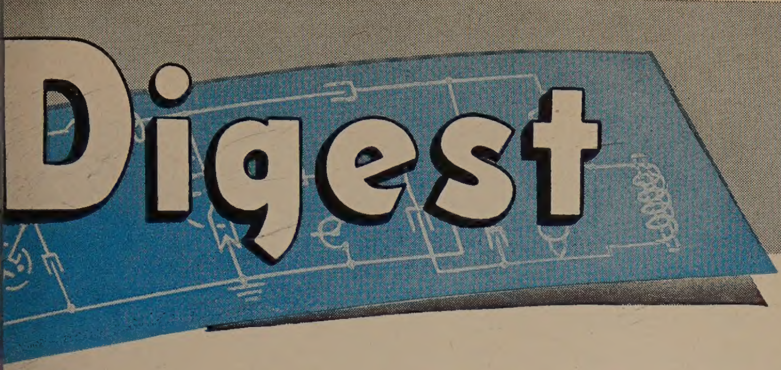

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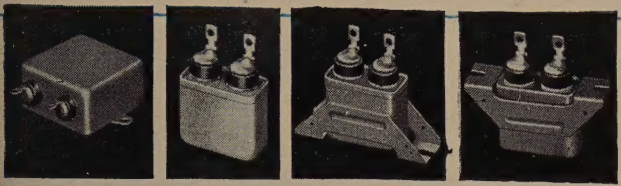

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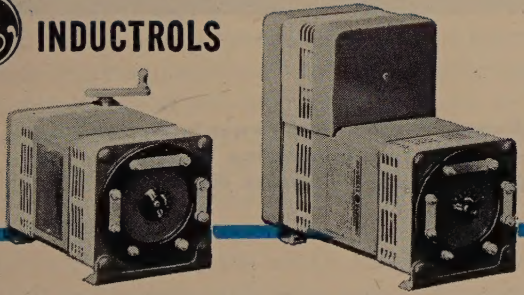

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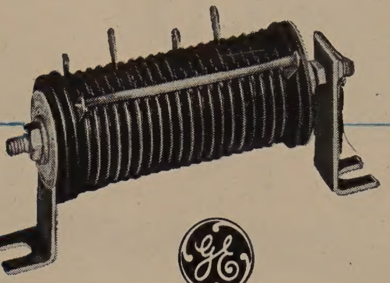

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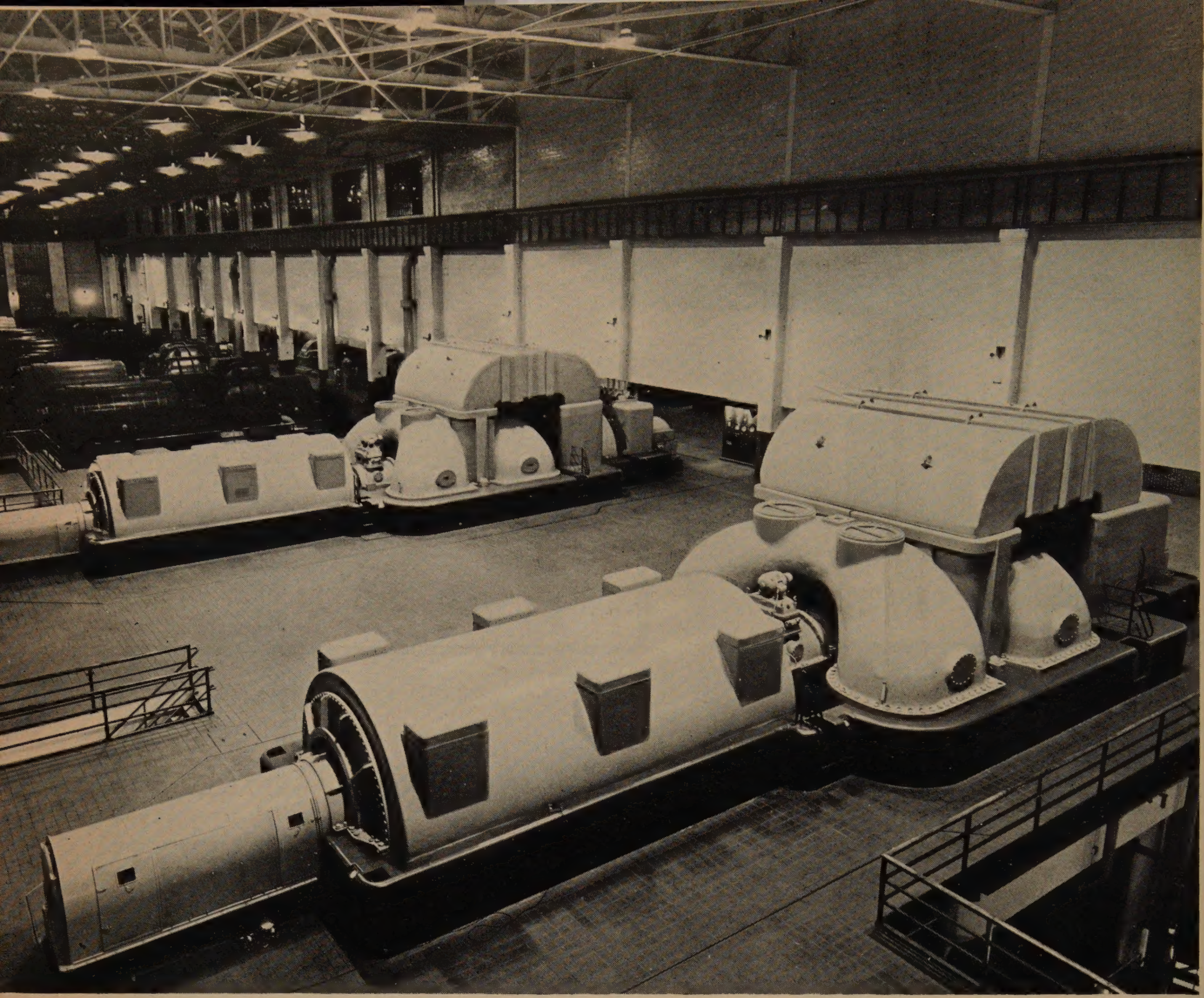


TANDEM-COMPOUND TEAM

Specimens of power equipment that characterize the More Power to America age. The turbines of the two 100,000-kw 1800-rpm generating units in the foreground have 23 stages and double-flow low-pressure elements *(See p. 29)*

ADDITIVES FOR LUBRICATING OILS

A survey of the nature and application of types that are of particular interest to the electrical industry. Their potentialities and limitations in their effects upon rust, oxidation, lubricity, viscosity index, pour point, and foam

By Dr. E. R. BOOSER
Bearing and Lubricant Center, Thomson Laboratory
General Electric Company, West Lynn, Mass.

E R Booser

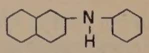
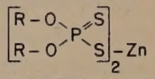
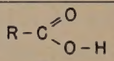
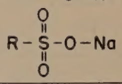
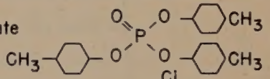
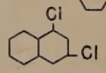
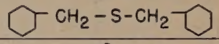
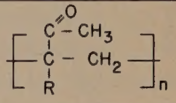
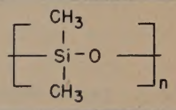
THE commercial application of chemical additives to lubricating oils began about 1930. The introduction of high-compression gasoline engines, high-speed diesels, hypoid automotive gears, and similar mechanical developments putting heavy demands on lubricants greatly speeded the development of these chemical agents designed to improve the properties of lubricating oils. Further work on improving oils through chemical additives has been intensified by the advent of higher speed, higher-powered engines and motors, and by such developments as jet propulsion, hydraulic control systems, and torque converters.

Chemical addition agents have been designed to improve almost any of the properties of the lubricating oil when required by machine design or operating conditions. In general these agents are specific chemical compounds added to the oil to alter one or more specific chemical or physical properties of the oil. Thus, there are oxidation inhibitors to improve oil stability, oiliness agents to improve lubricity, extreme-pressure agents to relieve welding tendencies in heavily loaded gears, rust inhibitors to prevent corrosion by moisture, pour-point depressants to reduce the lower temperature limit at which the oil will function, detergents to keep dirt from depositing on surfaces, and defoaming agents for suppressing foam. In some cases, such as with some extreme-pressure lubricants and rust-inhibited oils, the function of the additive has become so much more important than that of the oil in which it is carried that the oil itself serves little more purpose than merely that of a solvent or carrier for the additive.

At present there is an estimated fifty million pounds of these chemical additives produced annually in this country to treat some 40 million gallons of automotive crankcase oils, along with probably at least an equal quantity for turbines, hydraulic systems, railroads, aircraft, and other applications.⁽¹⁾ The use of additives is still increasing, and the potential market is estimated as being considerably more than two-hundred million pounds per year. Even this figure cannot take into account new mechanical developments of the future. Since petroleum-refining methods have very nearly reached perfection in providing highly purified hydrocarbon oils, almost all new demands on lubricant performance in the future will have to be met by new and increased application of additives to petroleum oil and by new combinations of additives with synthetic oils.

To understand more clearly the nature, functions, and potentialities of lubricant additives, consider in some detail a few of the more important classes of the materials. According to their relative importance in the electrical industry, these are taken up in the following order: oxidation inhibitors, rust inhibitors, lubricity agents, viscosity-index improvers and pour-point depressants, and defoaming agents. The general types of additives, their description, and typical chemical formulas are listed in Table I. Although many references have appeared in the literature concerning various phases of work on these lubricant additives in the past two decades, the list at the end of this article is largely limited to the past few years. This should prove an

TABLE I
GENERAL TYPES OF ADDITIVES
WITH TYPICAL CHEMICAL COMPOSITIONS

Type	Description	Typical Formula
Oxidation Inhibitor	Aromatic Amines	
	Metal Organo Dithiophosphates	 $\left[(R-O)_2P(=S)-S\right]_2-Zn$
Rust Inhibitors	Organic Acids	 $R-C\genfrac{}{}{0pt}{}{\diagup O}{\diagdown O-H}$
	Metal Petroleum Sulfonates	 $R-\overset{\overset{O}{\|}}{\underset{\underset{O}{\|}}{S}}-O-Na$
Lubricity Agent	Aromatic Phosphate	
	Chlorinated Naphthalene	
	Benzyl Disulfide	
Viscosity-Index Improver and Pour-Point Depressant	Alkyl Methacrylate Polymer	 $\left[\begin{array}{c} \overset{O}{\overset{\|}{C}}-CH_3 \\ \vert \\ -C-CH_2- \\ \vert \\ R \end{array}\right]_n$
Defoaming Agent	Silicone Oil	 $\left[\begin{array}{c} CH_3 \\ \vert \\ -Si-O- \\ \vert \\ CH_3 \end{array}\right]_n$

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

⁽¹⁾ Numbered references are listed at the end of the article.

adequate starting point for any more extensive study of the various subjects covered in the article.

Although the various types of additives will be considered individually, the benefits of several types can frequently be introduced into a single oil. Thus, some gear lubricants include extreme-pressure agents for improved lubricity, rust inhibitors to prevent corrosion, and agents to reduce the foam resulting from the churning action of the gears. On the other hand, additives do not always harmonize. Most rust inhibitors, for instance, are active promoters of oxidation and tend to counteract the effect of oxidation inhibitors. The situation is further complicated by variations in the effectiveness of additives in different types of oils. Ideal selection depends upon the extensive experimentation with various combinations conducted by laboratories such as those of our major oil companies.

OXIDATION INHIBITORS

Oxidation of the hydrocarbons present in lubricating oils by the oxygen of the air has been the subject of some recent investigations⁽²⁾⁽³⁾⁽⁴⁾ which indicate that all petroleum oils have a limited stability and that this stability is greatly decreased by modern refining methods that tend to eliminate naturally occurring oxidation inhibitors. Such petroleum oils frequently give only very short useful life in equipment, with acids, gum, sludge, and carbon formation resulting in poor operation and premature failure.

By adding synthetic inhibitor additives, the oxidizing tendencies of a lubricant can often be kept at a negligible value, as indicated in FIG. 1. The oxidation inhibitors used for this purpose consist of compounds which preferentially react with the activated oxygen molecules or hydrocarbon peroxides that normally would cause oil breakdown. A variety of compounds such as phenols, naphthols, aromatic amines, sulfur compounds, and selenium compounds can be used quite successfully for this purpose in concentrations of the order of only a half to one percent. Selection and concentration depends on the temperature level, metals present, type of oil, cost, and similar factors.

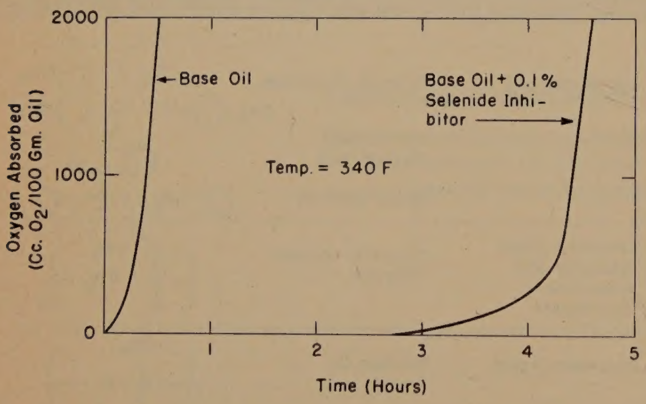


Fig. 1. Typical oxidation curves showing effectiveness of a small amount of an oxidation inhibitor in delaying the start of oil breakdown. (Curves from second Reference 3)

The effectiveness of these inhibitors in some applications is very great. The life of automotive oils can be increased from hundreds of miles to thousands, and that of turbine oils to many years; for instruments, clock motors, and small electrical equipment operating at moderate temperatures, oils can be given almost unlimited life. The rapid development of these additives, which are as yet applied only to some oils, has led to confusing ideas on lubricant life. The confusion has been emphasized by recent widely discussed articles in the popular literature on the desirable oil-change periods in automotive equipment.⁽⁵⁾

There are, of course, some limitations to the effectiveness of inhibiting compounds. There is, for instance, an upper temperature limit of about 160 C, above which the oxidation rate of ordinary petroleum oils becomes so great that simply inhibiting the rate of breakdown is no longer sufficient remedy for most applications. Occasionally the inhibitor may be chemically destroyed by the bearing metals or by contaminants in the lubrication system. Some types of oil filters will remove some types of inhibitors, leaving the oil unprotected. Most such limitations can be readily avoided, however, once they are recognized.

Familiarity with these inhibitors and their application is spreading rapidly. Almost all government specifications and many of those in industry stipulate minimum oxidation stability, and the use of oxidation-inhibited oils may become almost universal in the not-too-distant future.

RUST INHIBITORS

Second in importance among the lubricant additives for use in the electrical industry are rust inhibitors. Oils treated with such materials are used in a great variety of applications to prevent the rusting of iron and steel surfaces which are likely to be exposed, during storage or use, to water condensed from the atmosphere or to water leakage. An early application of this type of additive was in steam-turbine oils.⁽⁶⁾ During the war these rust-inhibited oils were used in aircraft hydraulic systems, for lubricating electrical and various other instruments, and for protecting machined ferrous parts such as tools, instruments, and aircraft engines.⁽⁷⁾

The chemical nature and function of this type of additive has recently been treated quite thoroughly in the literature.⁽⁷⁾⁽⁸⁾⁽⁹⁾ In general the additives are organic compounds with one characteristic in common: one end of the molecule is sufficiently polar to be adsorbed on the ferrous surface, while the other end is a large hydrocarbon group soluble in lubricating oil. When a rust-inhibiting oil is applied, an adsorbed layer of the polar rust-preventive molecules adheres to the vulnerable surface to form a semirigid lattice containing oil, as is suggested in FIG. 2. The combination of oil and the polar additive then hinders the ingress of water to the metal surface.⁽⁹⁾

Other rust-preventing additives act as emulsifiers.⁽¹⁰⁾ These enable the oil to take up small amounts of water from the metal surface before it has a chance to start rusting damage. The oil then surrounds the water and holds it as droplets in suspension in the main body of the oil, where it can cause no trouble.

The extent of rust-preventive action needed varies greatly in different applications. With steam-turbine oils, for example, only a fraction of one percent of weakly adsorbed compound such as stearic acid is sufficient. In fact, Dantsizen⁽⁶⁾ has indicated that after short-time use the oil will be satisfactorily rust-inhibited in itself because of the presence of sufficient protective polar compounds formed simply through oxidation of the oil.

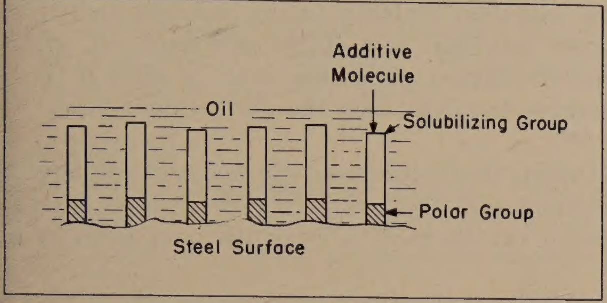


Fig. 2. Protective oil-additive network formed by polar rust-inhibiting molecules on vulnerable steel surface

Much more strongly inhibited oils are needed, however, to resist such leaching action of water as that occurring with atmospheric condensation. In such cases as this, the additive must be strongly polar to be able to build up an adsorbed layer of a thickness of about six molecular layers in order to impart rust protection.⁽⁹⁾ Typical of such inhibitors would be metal petroleum sulfonates, sorbitan mono-oleate, organic phosphates, and substituted organic acids. These are the types of material that are used for inhibiting hydraulic oils, instrument oils, and various preservative oils.

Indiscriminate use of rust inhibitors may be harmful, however. Many deteriorate rapidly at high temperatures. Some promote corrosion where dissimilar metals are in contact. Some cause accelerated oxidation of the oil, and even the best do bleed away in time from the metal surface under the continued leaching action of water, to leave it unprotected.

Even so, advances have been rapid in this field and the means are now available for completely eliminating many troublesome rust problems and thus saving some of the millions of dollars' worth of equipment currently being lost annually to the attack of rust.

LUBRICITY AGENTS

In many types of modern machinery the lubricating oil encounters loads, speeds, and clearances which result in the presence of only a very thin film of oil between sliding metal surfaces. This film is sometimes so thin that it is ruptured by high spots on the metal surfaces, with wear, pick-up, welding, and seizure occurring.⁽¹¹⁾ The tendency toward troublesome wear between metal surfaces under these conditions of so-called boundary lubrication can frequently be overcome by addition to the oil of polar compounds or of chemicals which react to form solid lubricants.

An explanation of the function of lubricity addition agents has begun to crystallize⁽¹¹⁾⁽¹²⁾⁽¹³⁾ in the past few years. When the severity of the lubrication problem is not too great, antiwear, or mild extreme-pressure additives are employed. These are polar compounds such as organic phosphates, phosphites, and chlorinated aromatics, which are strongly adsorbed on metal surfaces to give at moderately high loads a protective lubricant layer of high film strength over the metal high spots. Indication has been obtained that these adsorbed layers are extremely stable and rigid in character.⁽¹³⁾ This type of additive finds considerable use in oils for aircraft hydraulic systems, instruments, and refrigeration equipment. Its effectiveness in maintaining low friction when hydrodynamic lubrication breaks down is indicated in Fig. 3.

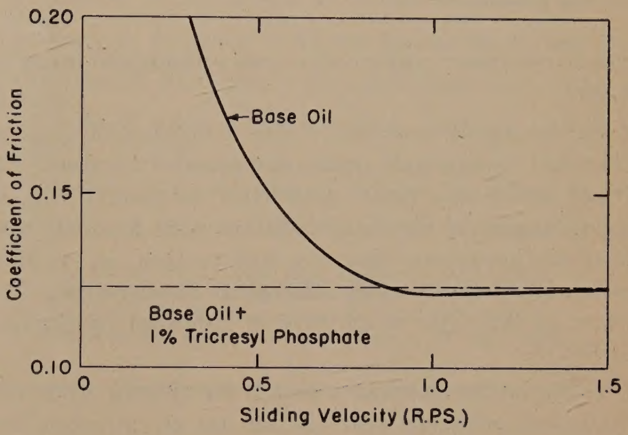


Fig. 3. Example of the reduction in friction made possible under severe rubbing conditions by the addition of a lubricity agent. Four-ball wear top; steel on steel. On abscissa, R.P.S. is Revolutions per Second of ½-in. ball. (Curves from Reference 13)

Where extremely high pressures and low sliding speeds are encountered, however, in applications such as some very heavily loaded bearings and in the hypoid gears in automobiles, even a strongly adsorbed film of lubricant cannot prevent metal-to-metal contact of the moving parts. In such cases extreme-pressure additives are employed. These appear to act by the formation of an easily sheared solid lubricant, produced by chemical reaction under the influence of the excessive local temperatures at contact points of high unit pressure, as indicated in Fig. 4.⁽¹⁾⁽¹²⁾ The solid lubricant prevents the welding together of the bearing or gear surfaces and thus prevents serious damage and eventual failure. Such solid lubricants include lead, lead sulfide, lead chloride, lead sulfate, and iron oxides, chlorides, and sulfides.⁽¹⁾ Only a few molecules of reaction product appear to be necessary to prevent metal-to-metal contact.

The extreme-pressure additives usually contain some combination of lead soaps, free sulfur, and rather reactive sulfur, phosphorus, and chlorine compounds.⁽¹²⁾ To prevent excessive attack on metals by these reactive chemicals, a corrosion inhibitor is sometimes included in the additive. At best, however, these additives do tend to be somewhat corrosive; and for that reason their use is usually avoided, except under extremely severe conditions of rubbing speed and pressure, in favor of the milder lubricity agents.

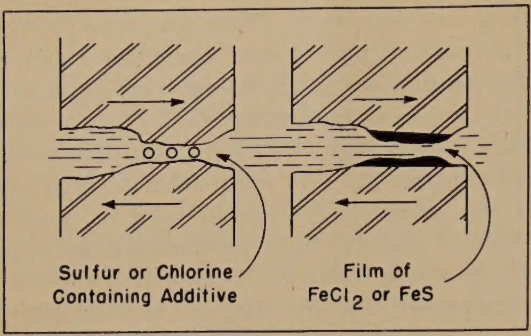


Fig. 4. Extreme-pressure agents form easily sheared protective surface layers of solid lubricants under the influence of the high local temperatures in heavily loaded bearings and gears. (Figure from Reference 1)

VISCOSITY-INDEX IMPROVERS AND POUR-POINT DEPRESSANTS

In the middle and late 1930's a number of types of chemical compounds were developed to extend the lower limits to which petroleum lubricants can be used. Similar or identical additives were found to give also an improved viscosity index—that is, a more constant viscosity with changing temperature. The effect of this type of additive is indicated by the plot in Fig. 5.

Early in the last war a search for aircraft hydraulic fluids and ordnance gear oils for use at extremely low temperatures led to the development of oils built around this type of additive. Such oils were used extensively by the armed forces during the war, and they still find extensive application in aircraft and hydraulic equipment.(14) More recently the additives have been finding widening use in some highly advertised motor oils which fill the needs of both summer and winter automobile driving.

The best of the pour-point depressants are high-molecular-weight oil-soluble polymeric compounds such as polybutenes, polymethacrylates, and alkylated polystyrenes.(14) Although the exact manner in which these additives function is not entirely clear, they are believed to lower the pour point by retarding the formation, on cooling, of a lattice-like structure of wax crystals. Such a lattice normally forms and traps the oil remaining in the liquid state, thus preventing it from flowing, or "pouring." The additives appear to become adsorbed from oil solution onto the surface of wax crystal nuclei as they form, and thus to prevent the normal growth of the wax crystals into a lattice network.(1)

The improvement in viscosity index can be effected by identical or similar polymeric additives.(14) The decreased effect of temperature on viscosity probably reflects the lesser influence of temperature change on the mobility of the polymeric molecules. The relativel huge polymeric molecules partially impart this property to the hundreds of small oil molecules in the field of influence.

Some difficulties have occasionally been encountere in the application of this type of additive. Under cond tions of severe mechanical shear, the polymer molecul are slowly broken down into smaller fragments.(1 The oxidation stability of the polymer is frequentl poorer than that of a stable petroleum oil, and th type of additive sometimes loses its effect if the temperature fluctuates near the normal pour point of th oil.(15)

Despite the limitations, some fine products have bee produced with these additives. As little as 0.5 weig percent can be used to lower the pour point of som oils as much as 50–60 F, and a few percent will giv oils with viscosity indexes of 150 to 160, values completely unattainable otherwise with petroleum oils.(14)(1

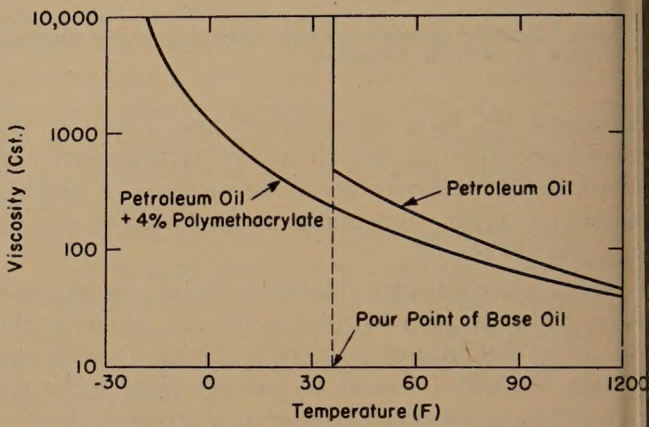


Fig. 5. Example of improvement that is obtainable in viscosity-temperature characteristics of oils with some polymer additives

DEFOAMING AGENTS

Oil foaming has sometimes constituted a problem i cutting oils, turbines, hydraulic systems, aircraft applications, and elsewhere where there is a tendency fo air to be churned into the lubricating oil. This foam sometimes becomes very troublesome. If, for example so much foam forms in the lubrication system that th circulating pump delivers only a supply of oil bubbles insufficient lubrication may result in bearing failures Foaming may also cause overflow from the oil reservoir and foam in the lines of hydraulic systems can destro normal operation.(10) Detergent-type oils in genera have greatly increased foaming tendency as compare with regular petroleum oils.(16)

Up until the middle 1940's the only means of reducin the trouble with foam was the use of settling tanks baffle arrangements, filter beds, or similar mechanica devices for breaking up the air bubbles. At that time however, the newly developed silicone oils were foun to be quite useful addition agents for dissipatin foam.(16) Their effectiveness is indicated by the plot i Fig. 6, comparing the foam obtained with and withou an added silicone defoaming agent.

The mechanism by which silicones break up foam is not clear. It seems probable that the low surface tension of silicones, having a magnified influence because of the low solubility of the silicone oil in petroleum oils, causes the surface film around the foam bubbles to be weak and thus to rupture easily. This action is probably entirely physical in nature and has been compared to that of a pin pricking a toy balloon.(10)

The amount of added silicone oil necessary for reducing foam is usually extremely small. As little as a few parts per million is frequently sufficient.(17)

OTHER ADDITIVES

In addition to the foregoing additives, which find rather extensive use in the electrical industry, a number of other types are finding considerable application. Detergents are widely used for heavy-duty automotive oils to help keep engine dirt and carbon deposits from settling out on engine parts. Emulsifiers help form stable emulsions of oil in water for steam-engine cylinder lubrication, and demulsifiers are employed to help avoid water in oil emulsions in steam turbines. Tackiness agents are used in some machinery applications to make lubricants sticky so they will stay in place better. Metal deactivators reduce the accelerating effect of metal surfaces on lubricant oxidation, and anticorrosion agents reduce the corrosive attack of oil oxidation products on metal surfaces.

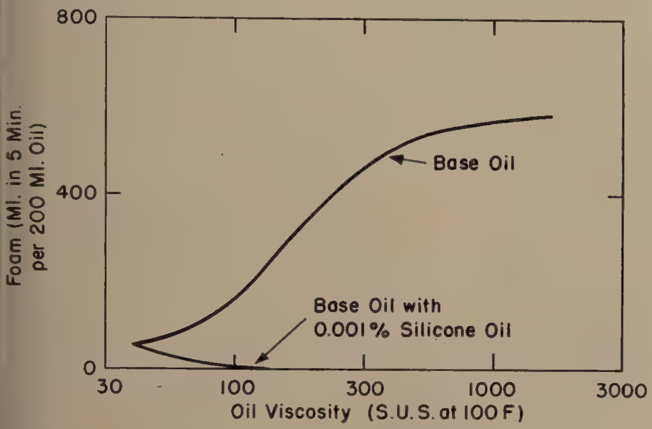


Fig. 6. Comparison of foaming of a lubricating oil with and without the presence of a methyl silicone defoaming agent. (Curves from Reference 16)

The eventual number of kinds of lubricant additives developed will probably be limited only by the number of types of service demands placed upon lubricating oils.

FUTURE TRENDS

Lubricant additives, being relatively new products, will probably be greatly improved in future years. Their past development has progressed so rapidly and successfully, however, that some already have become more important constituents of lubricants than the oil itself. In such cases the oil has little more purpose than simply that of a solvent for carrying the chemical additive. Since certain properties of petroleum oils make them rather limited in utility in this role of a carrier, additives will likely be employed more and more in combination with the new synthetic oils, such as those of the ester, polyglycol, and silicone types.

These will be the lubricants employed by the designers of machines in improving existing mechanisms. Even more important, these lubricants will be called on to lubricate rocket ships, atomic-energy machines, and other devices of the nebulous future.

REFERENCES

(1)Prutton, C. F., and Musgrave, F. F., *Chem. Eng. Progress, 45*, 17 (1949).

(2)Booser, E. R., Ph.D. Thesis, The Pennsylvania State College, 1949.

(3)Denison, G. H., and Harle, O. L., *Ind. Eng. Chem., 41*, 934 (1949).

Denison, G. H., and Condit, P. C., *Ind. Eng. Chem., 41*, 944 (1949).

(4)Zuidema, H. H., *Chem. Rev., 38*, 197 (1946).

(5)Manchester, H., *Reader's Digest*, 119, April 1949.

(6)Dantsizen, C., *Trans. ASME, 63*, 491 (1941).

(7)Baker, H. R., and Zisman, W. A., *Ind. Eng. Chem., 40*, 2338 (1948).

(8)Baker, H. R., Jones, D. T., and Zisman, W. A., *Ind. Eng. Chem., 41*, 137 (1949).

(9)Barnum, E. R., Larsen, R. G., and Wachter, A., *Corrosion, 4*, 3 (1948).

(10)*Chemical Additives for Petroleum Lubricants*, American Cyanamid Co., 1948.

(11)Sellei, H., *Petroleum Processing, 4*, 1003 (1949).

(12)Prutton, C. F., and Assef, P. A., *Ind. Eng. Chem., 41*, 960 (1949).

(13)Thorpe, R. E., and Larsen, R. G., *Ind. Eng. Chem., 41*, 939 (1949).

(14)Van Horne, W. L., *Ind. Eng. Chem., 41*, 952 (1949).

(15)Kalichevsky, V. A., *Petroleum Refiner, 28*, 97 (1949).

(16)Trautman, C. E., *Lubrication Engr., 2*, 143 (1946).

(17)Kalichevsky, V. A., *Petroleum Refiner, 28*, 125 (1949).

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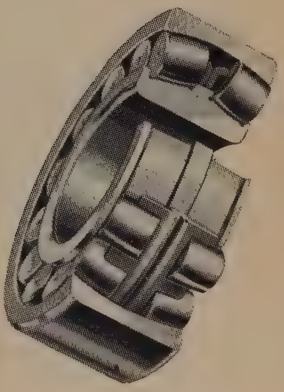

ORIENTED CRYSTALS: THEIR GROWTH AND THEIR EFFECTS ON MAGNETIC PROPERTIES

A widening knowledge of influences and resultant configurations in manufacture and processing of materials gives promise of control and effective utilization of specific properties

By WESTON MORRILL

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Weston Morrill

THE crystalline nature of metals has long been accepted as a fact by the metallurgist, although this perhaps has been less fully appreciated by others. A typical crystal structure of a sample of silicon-iron alloy is shown in Fig. 1. Within each individual crystal the atoms are arranged in an orderly pattern which repeats itself periodically in three dimensions. The fundamental pattern or simplest unit of such an orderly arrangement is called the unit cell of the crystal lattice.

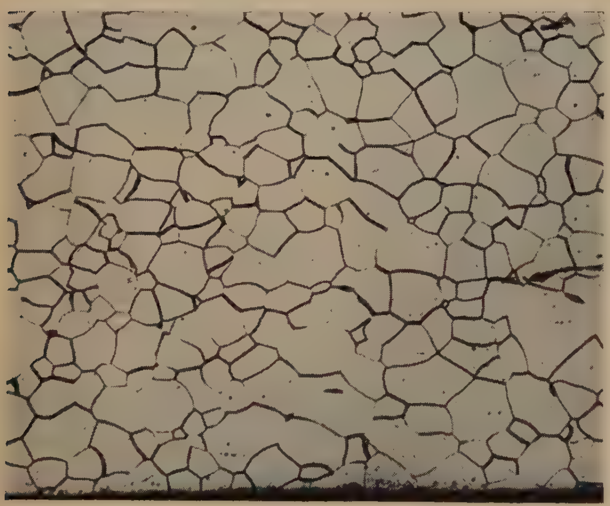

Fig. 1. Typical crystal structure of annealed silicon-iron alloy (×100)

CRYSTAL STRUCTURE AND MAGNETIC PROPERTIES

In iron and ferrous alloys, the unit cell consists of a cube having an atom at each corner and one at the center (Fig. 2). This crystal lattice structure has three principal axes: that along a cube edge, designated in terms of Miller Indices [100]; the cube-face diagonal direction, [110]; and the body diagonal-axis direction, [111]. This structure is frequently referred to as body-centered cubic for obvious reasons.

In ferromagnetic materials, all of the atoms in these orderly crystal lattices will have a definite magnetic influence upon each of their neighbors. In this respect they will react similarly to a group of bar magnets, for each atom has a definite magnetic moment due to its various electronic motions. Because of such magnetic forces within the crystal lattice, some atomic directions because of their configuration will react more easily than others to an externally applied magnetizing force. The resulting nonuniformity of magnetic properties with crystallographic direction is termed magnetic anisotropy.

For single crystals of iron, the observed magnetization curves for specimens excited either way along the principal crystal axes are also shown in Fig. 2. It will be noted that the six cube-edge directions [100] are those of easiest magnetization, the face-diagonal directions [110] are intermediate and the cube diagonals [111] are the most difficult directions of magnetization. While these data were obtained on a single-crystal specimen of pure iron, similar relationships of the same nature exist for uniformly oriented multicrystalline aggregates and for the various ferrous alloys.

In a similar manner for the metal nickel (Fig. 3), the unit cell of the lattice structure is cubic with an atom at each corner and an atom centrally located in each cube face. In this case the directions of easy magnetization are the eight cube diagonals [111]. Nickel alloys show interesting variations from this pattern, those of the Permalloy type showing extremely weak anisotropy, while alloys in the 50 percent nickel-

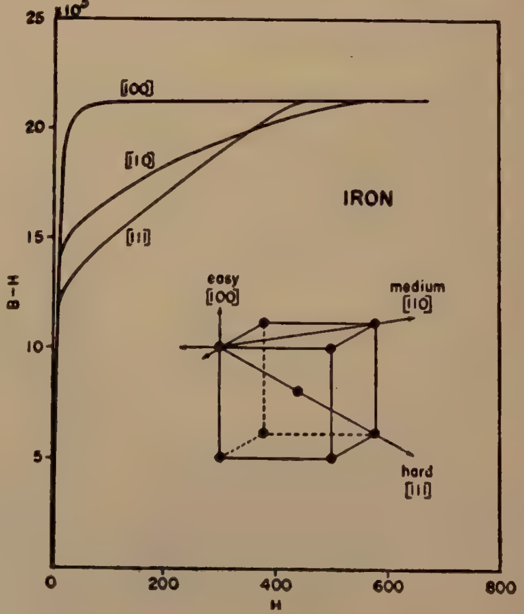

Fig. 2. Crystal-lattice structure of iron and typical magnetization curves (From K. Honda, et al.)

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Editor

50 percent iron range have a direction of easy magnetization either way along the cube edges [100] and the most difficult directions are the face diagonals [110].

An outstanding contribution to present-day magnetic properties is the practical development and utilization of this anisotropic property of metals. By orienting all the crystals of a metal in such a manner that one of their superior magnetic directions is parallel to the direction of magnetic flux path in useful structures, very exceptional properties may be obtained in that structure. Such a preferred crystal orientation is usually accomplished by the controlled growth of crystals following a complicated series of cold rollings and heat treatments, applied to carefully controlled chemical compositions. More information on the factors affecting the growth of oriented crystals in various magnetic materials will be presented later in this article.

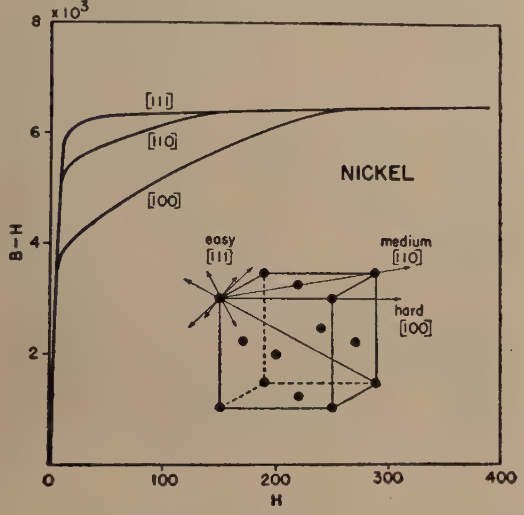

Fig. 3. Crystal-lattice structure of nickel and typical magnetization curves (From K. Honda, et al.)

SINGLE-CRYSTAL GROWTH

Single crystals of certain magnetic materials may be grown large enough to have some practical value as core structures. Williams of the Bell Telephone Laboratories⁽¹⁾ in 1937 prepared large single crystals of a 3.85 percent silicon-iron alloy. This was done by slow and directionalized cooling from a chemically pure melt. After the crystallographic directions of the specimen were determined, hollow parallelogram-shaped cores were so cut that each leg of the core was parallel to a [100] direction. The magnetic properties of such a structure after careful annealing, as revealed by Williams, are shown in Fig. 4. These values represent the highest permeabilities that we have ever noted for silicon-iron alloys, the maximum permeability being of the order of 600,000.

A more practical method for growing single crystals of silicon iron from commercial materials, in a form from which core laminations may be easily cut, has been described by Dunn of the Transformer and Allied Product Laboratory of General Electric Company.⁽²⁾ This method uses sheet material having controlled chemical composition and with a fine-grained crystal structure that will support the growth of a single crystal of the desired orientation. Control of the growth of the single crystal is gained by using a sharp high-temperature gradient through which the specimen is slowly moved, at a rate equal to the growth rate of the crystal.

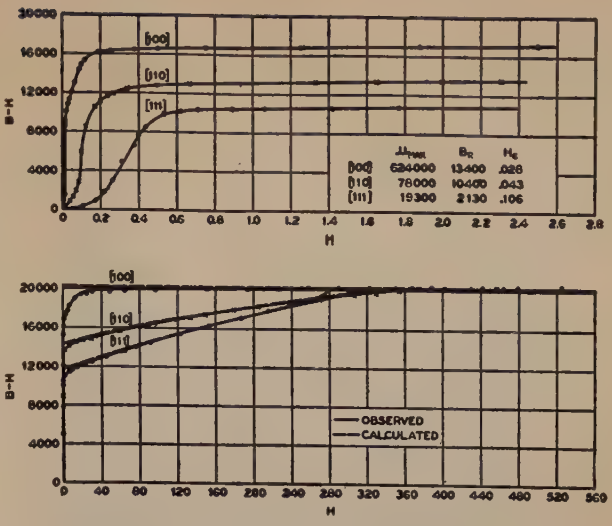

Fig. 4. Magnetic properties of high-purity single crystal of silicon-iron alloy (From H. J. Williams)

To obtain the desired orientation, the specimen is fed an inch or so into a gradient furnace, producing one or more crystals in the hot end (Fig. 5). The orientation of one of these crystals is then determined by x-ray analysis. This seed crystal is now isolated from the main body of the specimen (b) by grinding off all but a narrow neck of matrix material, following the dashed

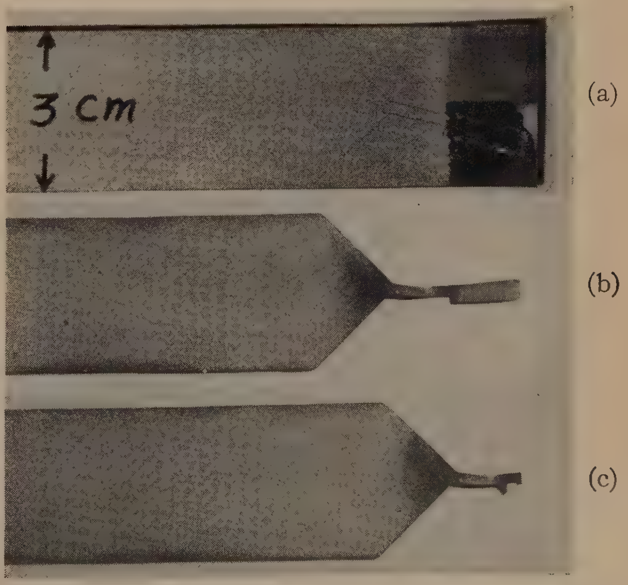

Fig. 5. Mechanism of growth of single crystal of silicon-iron alloy to a predetermined orientation (From C. G. Dunn)

(a). Large crystals grown in end of strip
(b). Seed crystal isolated from recrystallized matrix by neck
(c). Seed crystal reoriented with respect to sample by twisting neck in three directions.

⁽¹⁾Numbered references are listed at the end of the article.

line shown in (a). This neck is held at red heat while being twisted in three directions to reorient the seed crystal into the proper orientation relationship with respect to the specimen. Upon reinsertion of the seed crystal into the gradient furnace and gradually moving the specimen into the furnace, the seed crystal grows through the twists of the neck and immerges with its new orientation into the sample proper (c). This single crystal may now be made to grow continuously throughout the specimen by simply moving the sample slowly into the gradient furnace.

If such a single crystal is so grown that two [100] directions exist at right angles to each other in the surface of the sheet, hollow-square core laminations having each leg parallel to a [100] direction may be easily stamped. A small core made of such laminations would require a very high temperature anneal (over 1300C) to relieve properly all mechanical strain and to eliminate insofar as possible the chemical impurities normally present in commercial iron. However, even when annealed at the more reasonable temperature of 1175C in chemically pure hydrogen these core structures have shown maximum permeabilities near 200,000. This order of magnetic property may be valuable in cores for use in various control circuits.

POLYCRYSTALLINE MATERIALS

The production of a high degree of preferred orientation in polycrystalline materials is in some respects a considerably more complicated matter than the growth of the single crystal just described, for in this case the spontaneous nucleation and growth of thousands of crystals to an identical structure must be under precise control. With magnetic materials, to develop optimum properties, an added complication lies in the fact that recrystallization or grain growth must occur at high enough temperatures to erase completely all previous history of sample strain.

Of the various types of crystal development in metals, two are of prime importance in magnetic materials. When a metal is severely strained, as by cold rolling, for example, a fine fibrous crystal structure results. This structure usually exhibits some type of preferred crystal orientation as the result of the deformation accompanying a directionalized strain. The magnetic permeability of such a structure is always very poor, irrespective of type of preferred crystal orientation, because of the adverse effect of the locked-up rolling strains.

When such a rolled metal is raised to some relatively low temperature a myriad of new small crystals nucleate and grow. The resulting recrystallized matrix in some magnetic materials has a very high degree of preferred crystal orientation of a very favorable type. However, to utilize this favorable orientation magnetically it is necessary to relieve all internal strain by annealing at as high a temperature as possible. However, at some indeterminate high temperature a secondary recrystallization or grain growth frequently occurs. In some cases this secondary growth is highly to be desired, because its preferred orientation is favorable magnetically, while in other cases its growth is studiously to be avoided. The significance of these various crystal phenomena may be clarified by specific illustrations.

A magnetic material which is now attaining very wide commercial usage is crystal oriented, or anisotropic, silicon-iron strip(3). This material is produced from a carefully controlled melt of iron alloy by a critical series of cold reductions and heat treatments. The cold-rolled structure recrystallizes at relatively low temperatures to a fine-grained matrix which exhibits a minor degree of preferred crystal orientation. Upon further heating to temperatures between 900C and 1200C the highly directional residual rolling strains guide the growth of a secondary set of crystals which gradually swallow up all of the primary crystals. The major preferred orientation of these secondary crystals is such that a magnetically good, cube-edge direction is lined up parallel to the rolling direction of the strip material.(4)

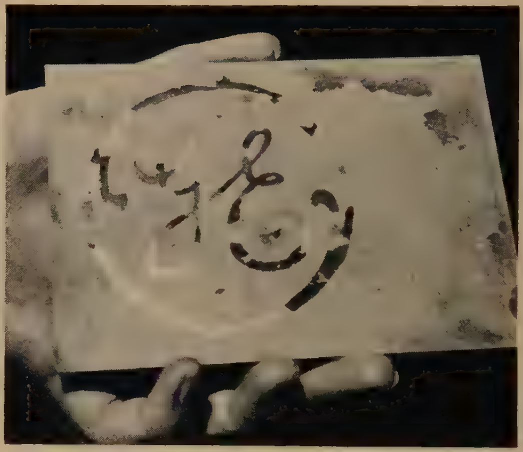
Fig. 6. Crystal growth control by nitrogen as shown by pattern shielded from its effects

The mechanisms which actuate crystal nucleation and growth are imperfectly understood and they are now the subject of intense research. The growth of crystals with a single preferred orientation in silicon iron is the result of many forces, including mechanical and chemical strain differentials, grain boundary energies as affected by orientation relationships and as altered by chemical impurities at the boundaries, and other factors less obvious.

EFFECTS OF IMPURITIES

The unavoidable presence of certain dissolved or atomically dispersed chemical impurities, situated interstitially in the silicon-iron lattice, may set up radial strains of chemical origin. Metallurgically, such a confused strain situation, superimposed upon the preferred strain introduced by cold rolling, may alter greatly the preferred crystal growth usually accompanying heat treatment of cold-rolled silicon iron. On the other hand, the absence of chemical impurity, if such were possible, would remove certain energy barriers to the growth of poorly oriented crystals. In such a case the promiscuous growth of crystals of many orientations, in addition to the dominant preferred orientation, unfortunately might be encouraged. The mechanism for such growth probably operates through alteration of grain-boundary energies.

However, in the purer alloy, the absence of any misguiding strain of chemical origin is a factor favorable to growth of crystals of one orientation. The ideal commercial strip material, therefore, should have a complete absence of any impurities except those which act as deterrents to the growth of poorly oriented crystals. The attainment of such an ideal state is difficult, if not impossible, since certain impurities cannot be reduced by any normal technical process and others are necessary for successful rolling of the sheet. Furthermore, knowledge is far from complete on the physical metallurgical functions of many alloy impurities.

TABLE I: EFFECT OF GRAIN DIRECTION ON A-C CORE LOSSES OF CRYSTAL-ORIENTED SI-FE STRIP IN WATTS PER POUND AT 60 CYCLES

Peak $B = 15{,}000$ gausses ($= 96.78$ kilolines per sq. in.)

With grain	0.700
10 deg. angle to "with grain"	0.750
20 " " " "	0.875
30 " " " "	1.080
40 " " " "	1.420
50 " " " "	1.365
60 " " " "	1.320
70 " " " "	1.360
80 " " " "	1.295
90 " " " "	1.245

The crystal-growth-retarding effect of nitrogen as demonstrated by Dunn and Johnson(5) is most interesting, and may be easily illustrated(6). Thus in FIG. 6, a piece of commercial silicon iron as cold-rolled and recrystallized to a fine-grained matrix, all of the area outside of the G-E monogram has been artificially nitrided to a slight degree, while the area of the letters and the circle were protected from nitrogen. In the subsequent heat treatment, large, well-oriented crystals grew to fill the monogram while no crystal growth developed in the nitrided background.

Carbon (and probably oxygen, also) which, like nitrogen, assumes an interstitial position in the iron lattice similarly alters the growth of oriented crystals. However, unlike nitrogen which normally exists in commercial irons in amounts which do not seriously affect good crystal development, carbon cannot be reduced sufficiently during commercial melting processes. Good melting practice will eliminate carbon to some value under 0.03 percent, while good crystal development requires less than one-fifth this amount. Consequently, regular processing of oriented cold-rolled silicon-iron strip requires that carbon be reduced to 0.006 percent or less before orienting crystal growth is attempted.

Other impurities normally present in commercial iron-silicon alloys exhibit quite different types of crystal-growth-retarding effects. This applies to materials considered to be entirely insoluble in iron. For example, aluminum oxide sometimes produced in colloidal suspension in steels deoxidized with aluminum will alter grain growth to a point where the final annealed product may be characterized by a few extremely large crystals, many of which will be poorly oriented. It may be postulated that alumina, in addition to deterring the growth of most crystal nuclei (which accounts for the few large crystals), cancels to some extent the energy advantage enjoyed by well-oriented crystals in their process of growth (which accounts for the poor orientation).

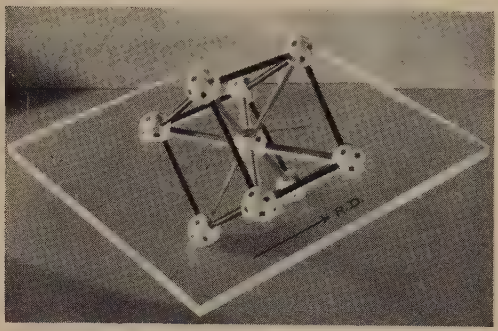

Fig. 7. Crystal-lattice structure of oriented silicon-iron strip

DEVELOPMENT OF CRYSTAL STRUCTURE

The crystal-lattice structure of oriented silicon-iron strip is of the type illustrated in FIG. 7. It will be noted that the strip surface contains one good magnetic direction [100] parallel to the strip length. However, the strip surface also contains the poorer magnetic crystal axes, [110] and [111], so that the direction of magnetic flux in apparatus cores should avoid these directions where possible. The effect of crystallographic direction on d-c magnetic tests is illustrated by the magnetization curves in FIG. 8; on a-c core losses at 60 cycles, 15000B, in Table I. These data demonstrate that in crystal-oriented materials the alignment of the lattices from crystal to crystal must approach within

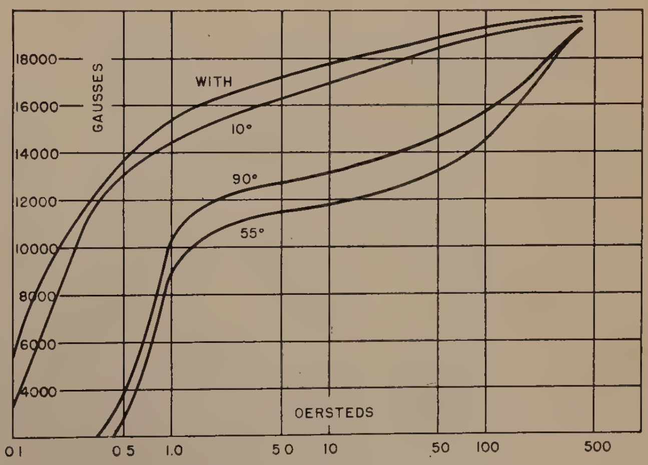

Fig. 8. Effect of grain direction on d-c magnetization of crystal-oriented silicon-iron strip (Directions are indicated in reference to "with grain")

a few degrees of perfection to attain full magnetic advantage of the anisotropic properties. It is obvious that the unidirectional character of this material imposes severe limitations upon its use in many types of core structures and frequently complete redesign is necessary to make full use of this material's unique characteristics.

The superior magnetic properties which have just been outlined, as well as those which will be mentioned later, have been obtained by control of chemical purity and through strain-free or delicately balanced, strain-controlled, conditions. Such a situation may easily defeat itself in practical situations; highly developed magnetic materials are veritable sponges for reabsorbing the factors from which they have been carefully freed. The engineer who specifies the best possible properties in his designs must recognize that he has a handling problem for his core structures if he expects to retain these properties in his completed apparatus. However, entirely practical processes for handling these sensitive materials in manufacture may be worked out and their sensitivity should in no way deter their use.

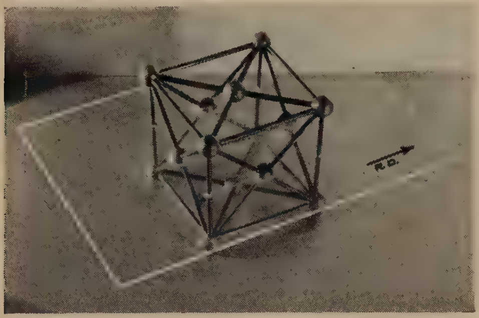

Fig. 9. Crystal-lattice structure of oriented 50 percent nickel-iron strip

TABLE II: TYPICAL MAGNETIC PROPERTIES* OF ORIENTED-CRYSTAL NI-FE ALLOY STRIP (0.002-IN. DELTAMAX)

B_p at $H = 15$	15,500 gausses
B_r (residual)	14,700 "
B_r/B_p	0.95
μ_{max} (permeability) at $B = 13{,}000$ gausses ($B_{\mu\ max}$)	125,000
$B_{\mu\ max}/B_p$	0.85
H_c (coercive force)	0.08 oersteds

*Note: These properties develop as a result of crystal structure alone. Heat treatment in a magnetic field will improve them in many cases.

The second illustration of preferred crystal development of importance to magnetic materials is that of the oriented crystal 50 percent nickel-iron alloy⁽⁷⁾ variously named Deltamax, Permeron, Permenorm, Orthonol, Orthonik, etc. This is an alloy of controlled purity in the form of thin-gauge cold-rolled strip, having a final cold reduction of 98 percent. Because of such extremely high directional strains, this material recrystallizes at relatively low temperatures to a fine-grained highly oriented matrix. The fundamental crystal lattice structure resulting (FIG. 9) is so oriented that two good magnetic directions lie in the surface of the sheet, one parallel to the direction of rolling and the other 90 deg to the rolling direction. The magnetic properties of this alloy recrystallized at low temperature show some of the characteristics of highly oriented crystals, obscured by residual strain effects (FIG. 10, curve A).

STRAIN RELIEF

Following recrystallization, the relief of rolling strain in Deltamax is a critical matter requiring the highest possible temperatures in an atmosphere of chemically pure hydrogen. However, at some temperature which varies from lot to lot, depending upon the chemical nature of the metal, a secondary crystal growth having an unfavorable preferred orientation occurs. Unlike oriented silicon iron where this secondary growth of crystals is encouraged, the optimum properties of Deltamax are obtained by approaching, but never quite attaining, this temperature of secondary crystal growth. In oriented silicon-iron strip, the chemical impurities are adjusted to encourage the complete growth of secondary crystals at lower temperatures. In Deltamax, similar impurities are set to work to increase the temperature of secondary growth to above the maximum point for satisfactory strain relief of the metal. Yet at the same time the presence of excessive chemical impurity in the final product must be avoided because of the adverse effect of chemical strain on magnetic properties.

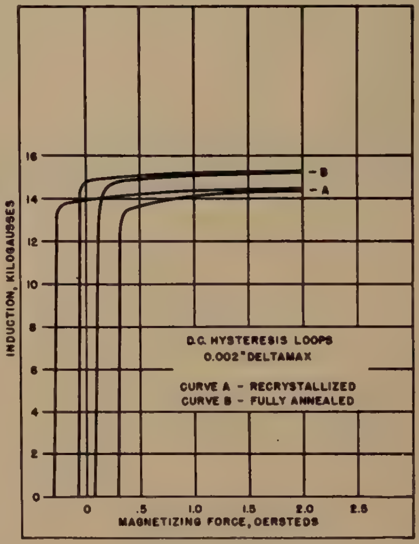

Fig. 10. D-c hysteresis loops of 0.002-in. Deltamax

When a satisfactory combination of chemical impurity and annealing temperature is attained, static hysteresis loops may be obtained on Deltamax core structures as shown in FIG. 10, curve B. Since the preferred crystal orientation of Deltamax allows two magnetically equivalent surface directions, the rectangular shaped hysteresis loop and the typical magnetic properties, given in Table II for 0.002-in. material, may be made available in core structures other

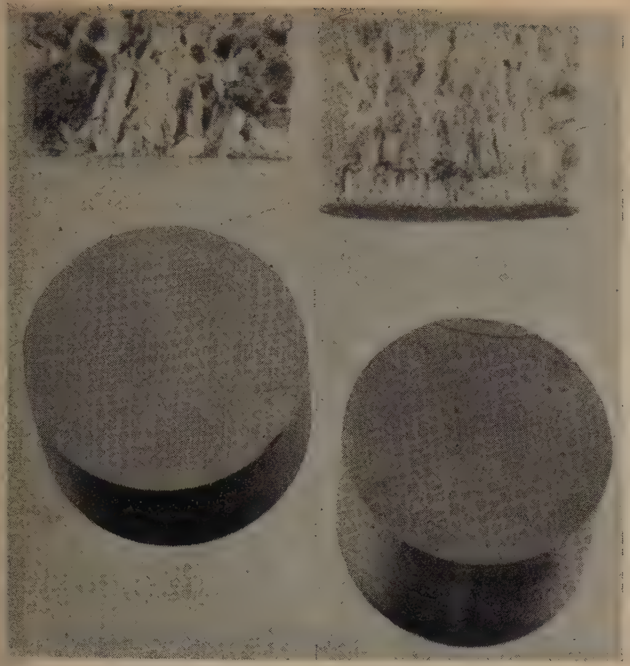

Fig. 11. Crystal structure of alnico 5 (*left*) and directional-grain alnico 5 (*right*)

than toroidally wound spirals. Such easily saturable low-loss magnetic materials may be very effectively designed into magnetic amplifiers, saturable reactors, and various types of control circuits, radar pulse transformers, computing machines, and many other devices.

The various oriented polycrystalline structures which have been described earlier in this article have developed as a result of directional cold-rolling strains. Smoluchowski and Turner working at Carnegie Institute of Technology have been able to create oriented structures in iron-cobalt alloys by recrystallizing in the presence of a directional magnetic stress, the strain of which we call magnetostriction(8). No magnetic tests upon samples prepared in this manner have been published. However, the type of preferred crystal orientation apparently developed in cold-rolled samples recrystallized in a magnetic field parallel to the rolling direction will produce two [100] directions at 45 deg to the rolling direction, with a good magnetic direction probably parallel to the rolling direction.

The principle involved in this type of recrystallization may be applied to any magnetic material which recrystallizes below the Curie temperature and which is subject to substantial alteration of length under the influence of an applied magnetic field. Both the oriented silicon-iron alloys and the 50 percent nickel-iron alloy fall into this classification. It will be interesting to note what may be done to the preferred crystal orientation of these alloys when they are recrystallized under the influence of a strong magnetic field.

PERMANENT-MAGNET MATERIALS

Turning from soft to hard or permanent-magnet materials, the development of a preferred crystal growth in alnico-type alloys has aided in producing a magnet with considerably increased energy. This new product is the result of directional grain growth during solidification, the columnar grains shown in Fig. 11 developing from crystal nuclei formed at a chill-plate surface when the liquid metal is cast into the mold. These elongated crystals have a good magnetic direction parallel to their long dimension. When fully magnetized parallel to the crystal columns, the directional-grain alnico has considerably higher energy values than is possible with the random crystal structure of ordinary alnico. When measured parallel to the preferred axis of magnetization, typical properties of directional-grain alnico are as recorded in Table III.

TABLE III: TYPICAL MAGNETIC PROPERTIES OF ALNICO 5 AND ALNICO 5 DG

	ALNICO 5	ALNICO 5 DG
Peak H (oersteds)	3000	3000
Peak B (gausses)	16,500	17,100
Residual, B_r (gausses)	12,600	13,100
Coercive force, H_c (oersteds)	600	640
$(B_d\ H_d)_{max}$	5×10^6	5.5×10^6
at $B_d =$	9800	10,400
at $H_d =$	510	530

CONCLUSION

The practical use of the anisotropic properties of metals is well advanced. The controlled growth of oriented crystals has produced in commercial materials magnetic properties which otherwise would have been simply laboratory curiosities. But much work must yet be done. The cheapest and most widely used magnetic material, common iron, has yet to yield the secret for orienting its crystals by any practical process. The best metallurgical laboratories in the country are studying the fundamentals of crystal nucleation and growth. In the end it is to be hoped that any desired preferred crystal orientation may be uniformly and cheaply produced at will in any magnetic material by practical commercial methods.

REFERENCES

(1)"Magnetic Properties of Single Crystals of Silicon Iron," by H. J. Williams, *Physical Review*, vol. 52, October 1937, p. 747.

"Growing and Processing of Single Crystals of Magnetic Metals," by J. G. Walker, H. J. Williams, and R. M. Bozorth, *Rev. of Scientific Instruments*, vol. 20, December 1949, p. 947.

(2)"Controlled Grain Growth Applied to the Problem of Grain Boundary Energy Measurements," by C. G. Dunn, *Jour. of Metals Transactions*, January 1949, p. 72.

(3)"Crystal Orientation in Magnetic Alloys," by Martin Littman, *Electrical Engineering*, vol. 68, November 1949, p. 977.

(4)*Cold Working of Metals*, Am. Soc. for Metals, Cleveland, Ohio, 1948, p. 113–130.

(5)*Cold Working of Metals*, Am. Soc. for Metals, Cleveland, Ohio, 1948, p. 123.

(6)"Improved Silicon Irons for Electrical Equipment," by W. Morrill, *Metal Progress*, vol. 54, November 1948, p. 676.

(7)"Deltamax, The Metal with a Brain," by W. S. Spring, *Steel Horizons*, vol. 11, no. 4, 1949, p. 16.

"Magnetic Characteristics of an Oriented 50 Percent Nickel-iron Alloy," by J. H. Crede and J. P. Martin, *Jour. of Applied Physics*, vol. 20, October 1949, p. 966.

(8)"Influence of Magnetic Field on Recrystallization," by R. Smoluchowski and R. W. Turner, *Jour. of Applied Physics*, vol. 20, August 1949, p. 745.

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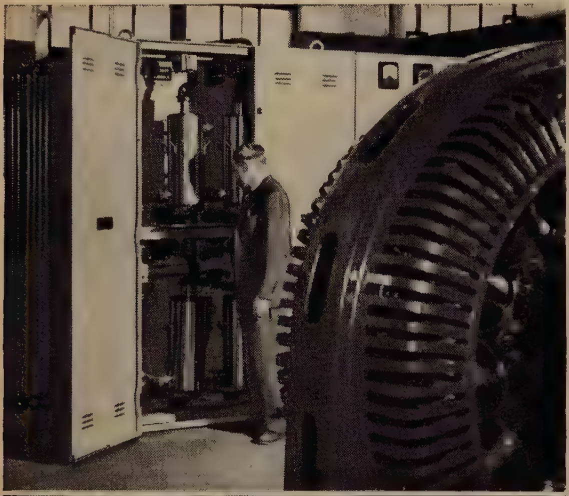

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MAINTENANCE OVER-POTENTIAL TESTS FOR ARMATURE WINDINGS IN SERVICE

After considerable investigation based on many years of experience, these armature-winding over-potential maintenance tests are offered as a practical guide to users of rotating machines

By R. W. WIESEMAN

Large Motor and Generator Engineering Division, Apparatus Dept.
General Electric Company

R. W. Wieseman

FOR nearly 40 years the accepted over-potential proof test for *new* armature windings of all types (a-c and d-c) above 50 volts has been twice normal voltage plus 1000 volts for 1 minute. The over-potential test to be applied to armature windings in service, however, has been somewhat of a controversial subject: test voltages vary from normal voltage to twice normal voltage depending on the machine voltage, service conditions, age, and the insulation strength the operator wishes to maintain; the duration of this test varies from a few seconds to one minute. The object of this article is to offer recommendations for appropriate over-potential tests for all types of a-c and d-c armature windings in service.

The service record of a rotating electrical machine depends to a great extent on the performance of its winding insulation. Proper installation, suitable overvoltage and overload protection, normal operating conditions, and periodic inspection and testing all help the machine windings to function satisfactorily. However, windings in service are continually exposed to such adverse factors as conducting dirt, moisture, chemical action, mechanical damage, abnormal temperature, overloading, and overvoltages. It is, therefore, desirable to occasionally apply a conservative over-potential test, after inspection and cleaning, to determine the suitability of a winding for continued service. By making these tests at the beginning of planned station overhaul periods, time will be available to replace any defective coils with spare coils without loss of service time. In this way, unexpected repairs made under costly emergency conditions may be avoided. Frequent or prolonged over-potential tests and test voltages higher than those outlined in this article are not recommended.

ARMATURE WINDING INSULATION

An inventory of armature winding insulation will disclose a dry-type laminated structure consisting of many varieties of materials bonded and filled by different processes. Winding insulation does not have the benefit of a waterproof enclosure, or a metallic ground sheath to prevent the entrance of foreign matter. Machine ratings vary greatly in power, power factor, voltage, speed, and frequency. These variations result in an almost unlimited number of different sizes and shapes of coils or bars to be assembled in slots and connected to one another permanently. Machines also vary in construction with reference to creepage distances, methods of winding support and end bracing, and arrangement and spacing of the end connections, as shown in FIGS. 1 and 2. Armature coils, and to a lesser degree armature bars, undergo a certain amount of deformation during slot assembly; and unless they are handled by skilled winders, insulation damage may result. Notwithstanding these many varieties of machines, windings, coils, and bars, simple tests are desired which will indicate the suitability of all types of armature windings for service.

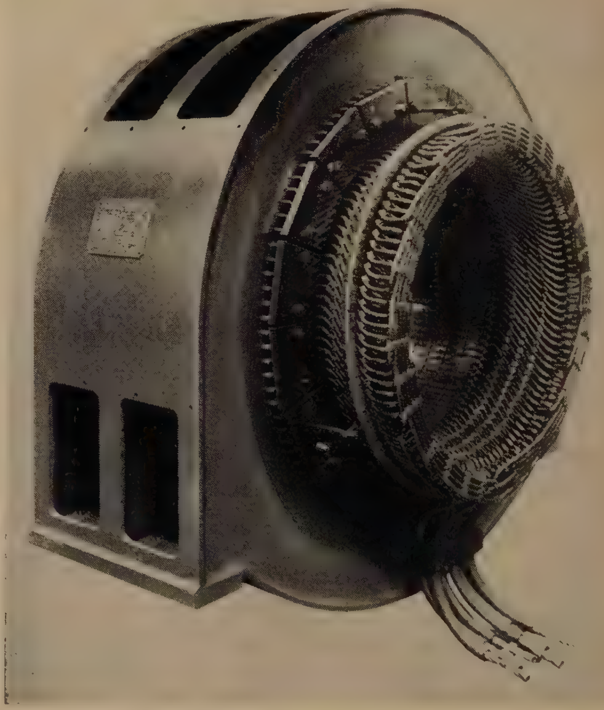

Fig. 1. Winding support and bracing of a synchronous-machine stationary armature winding

ARMATURE WINDING INSULATION TESTING

When transmission-line insulators are tested, they are tested individually and faulty insulators are usually detected. When an armature winding is tested, however, from 30 to 600 coils or bars are tested in multiple

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This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

as a group. Since service testing of armature coils individually is not practical, any kind of a single-reading qualitative test on the entire winding cannot give a good picture of the insulation condition of its individual components.

Insulation resistance, power factor, polarization, ionization, and capacitance are qualitative nondestructive tests which show the *trend* of the insulation condition. A high value of insulation resistance$^{(1)}$, for example, is usually indicative of clean, dry insulation; but it is not by itself proof that the insulation is free from mechanical weakness or that it has sufficient voltage strength. An over-potential test indicates that at the time the test was made, but not necessarily thereafter, the winding had a certain voltage strength. Nevertheless an over-potential test is the only test which will indicate whether a winding has sufficient voltage strength for service.

PREPARATION FOR OVER-POTENTIAL TEST

Before an over-potential test is applied, the winding should be inspected and, if necessary, cleaned and dried as follows:

Visual Inspection

Foreign particles sometimes find their way into the air gap and in or around a winding. During installation, inspection, and overhauling, workmen may carelessly step on the end portion of the winding of a large machine or allow objects with sharp edges to strike the winding. This may be the cause of some unexplained winding failures, since the evidence is usually destroyed by the failure. Nothing can replace a thorough visual inspection of the winding and core to detect the presence of foreign objects or mechanical damage before an over-potential test of any kind is made.

Cleaning and Drying

Unless a winding is relatively clean and dry, over-potential tests should not be made. Machines whose windings have accumulated considerable harmful foreign matter, such as conducting dirt, should be disassembled and thoroughly cleaned. Winding damage caused by rough handling and careless cleaning should be avoided.

A low insulation resistance resulting mostly from surface moisture does not necessarily indicate that the insulation is unsuited for operation, especially if the insulation resistance is comparable to that obtained from recent periodic tests. The increased winding temperature resulting from normal operation will expel the moisture from the winding if maintained for sufficient time with the machine suitably ventilated. Although the machine in this case may be suitable for service, it may not be advisable to apply an over-potential test until the winding is dried and its insulation resistance brought up to the normal value.

Windings which have accumulated considerable moisture should be dried by circulating current at low voltage in the windings or by heaters until the insulation resistance reaches the normal value. Sufficient heat should be provided to obtain a temperature of 75 C by thermometer on the end windings or 90 C by resistance temperature detector. For machines which have been flooded, a slowly increasing temperature up to 110 C maximum is suggested to accelerate drying.

OVER-POTENTIAL TEST FOR ARMATURE WINDINGS IN SERVICE

For a machine operated under normal conditions with rated line-to-line rms voltage E, the maximum rms voltage to ground at the armature winding terminals is given in Table I. If an a-c armature winding

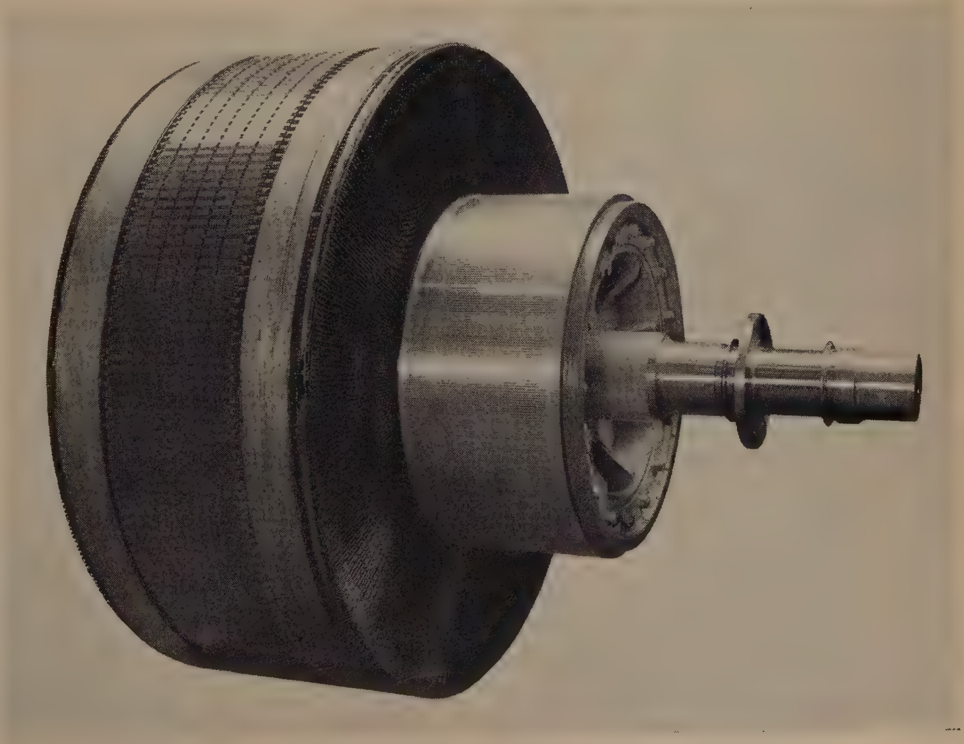

Fig. 2. Winding support and creepage paths of a direct-current machine rotating armature winding

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(1)Numbered references are listed at the end of the article.

TABLE I: NORMAL ARMATURE WINDING MAXIMUM RMS VOLTAGE ABOVE GROUND

A-c Armatures	Voltage above Ground
*Three-phase Wye Isolated Neutral	$E/\sqrt{3}$
Three-phase Wye Grounded Neutral	$E/\sqrt{3}$
*Three-phase Delta Ungrounded	$E/\sqrt{3}$
*Two-phase—Four-wire Ungrounded	$E/\sqrt{2}$
D-c Armatures	
*Ungrounded	E/2
Grounded Terminal	E

* Insulation resistance and capacitance assumed to be uniform throughout the entire windings.

is operated grounded as in Table II, the maximum rms voltage to ground at the winding terminals is considerably higher than that in Table I. For standard machines, the operating conditions shown in Table II are abnormal, and they should be avoided. If a winding has been designed to operate grounded as indicated in Table II, it will have additional insulation and its over-potential test should be increased accordingly.

Any voltage greater than the normal voltage to ground (Table I) constitutes an over-potential test on a standard winding. Since windings in service are subjected to increased voltages caused by load variations, speed changes, and surge voltages of varying amplitudes, the voltage of an over-potential test should be somewhat greater than the rated line-to-line voltage E. To verify that an armature winding is in good condition for continued service, experience indicates that the a-c over-potential test voltage should be about two thirds of the a-c proof test ($2E+1000$ volts for 1 minute) for a new winding or approximately

$1\frac{1}{3}E+600$ volts (1)

This a-c over-potential test applies to integral-kw a-c and d-c armatures above 50 volts for usual service conditions. Windings designed for special conditions may require a higher test voltage. On large Class B insulated armature windings, some users prefer a 10 percent higher test voltage than that indicated by Equation (1). A test voltage of only a given percentage of the winding normal voltage is not recommended because the test voltage obtained in this manner will not apply to both low- and high-voltage windings.

Recommended Practice for Maintenance Over-potential Tests

ARMATURE WINDINGS

Installation of Replacement Coils or Bars

When an armature winding is to be repaired and some new coils or bars installed, the winding should first be given an initial a-c over-potential test of

$1\frac{1}{3}E+600$ volts (1)*

in order to locate and remove all weak or defective coils or bars. After the repairs have been completed, the work may be checked by applying an a-c over-potential test of

$1\frac{1}{4}E+500$ volts (2)*

Suitability of Winding for Service

If an over-potential test is to be applied occasionally to an armature winding in service to check its voltage strength, the a-c voltage test should be in the order of

$1\frac{1}{5}E+400$ volts (3)*

For example, a 13,800-volt armature winding should be tested at about 17,000 volts.

The over-potential test voltages, in Equations (1), (2), and (3), are the test voltages to ground. On an a-c armature winding, the same voltages should be used for a phase-to-phase test with two phases grounded. FIG. 3 shows the relation between the test voltage for a new armature winding, the test voltage for an armature winding in service, and the winding normal operating voltage to ground.

TABLE II: ABNORMAL ARMATURE WINDING MAXIMUM RMS VOLTAGE ABOVE GROUND

A-c Armatures	Voltage above Ground
Three-phase Wye Grounded Terminal	E
Three-phase Delta Grounded Terminal	E
Two-phase—Three-wire Grounded Neutral	E
Two-phase—Three-wire Grounded Terminal	$\sqrt{2}E$

FIELD WINDINGS

The recommended a-c over-potential test voltages for field windings in service of integral-kw machines above 50 volts are given in Table III.

DURATION OF APPLICATION OF THE TEST VOLTAGE

For all over-potential tests the voltage should be applied to the winding for one minute.

WINDING TEMPERATURE

When a service over-potential test is to be made, the winding temperature should not be below room temperature, and preferably not above 40 C.

ALTERNATING-CURRENT OVER-POTENTIAL TEST

At power frequencies, the a-c test has been used extensively and it is the test with the greatest background of experience. The induced voltage in both a-c and d-c armature windings is alternating and so it is natural to test windings with an alternating voltage.

The test voltage should be relatively free from harmonics. A sphere gap should not be used in the winding circuit because it may produce harmful surge voltages if an arc-over occurs. The testing equipment and power supply should have ample capacity, and good voltage stability over its entire voltage range.

For small armatures, the charging kva required for a service over-potential test is relatively small. The 60-cycle charging kva for the service test of large armatures may be as much as 400 kva if the entire winding is tested.(2) Thus considerable equipment is required to make an a-c test on large units. Table IV gives the approximate kva required to test 13,800-volt armatures

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* On large Class B insulated armature windings some users prefer a 10 percent higher test voltage than that indicated by Equations (1), (2), and (3).

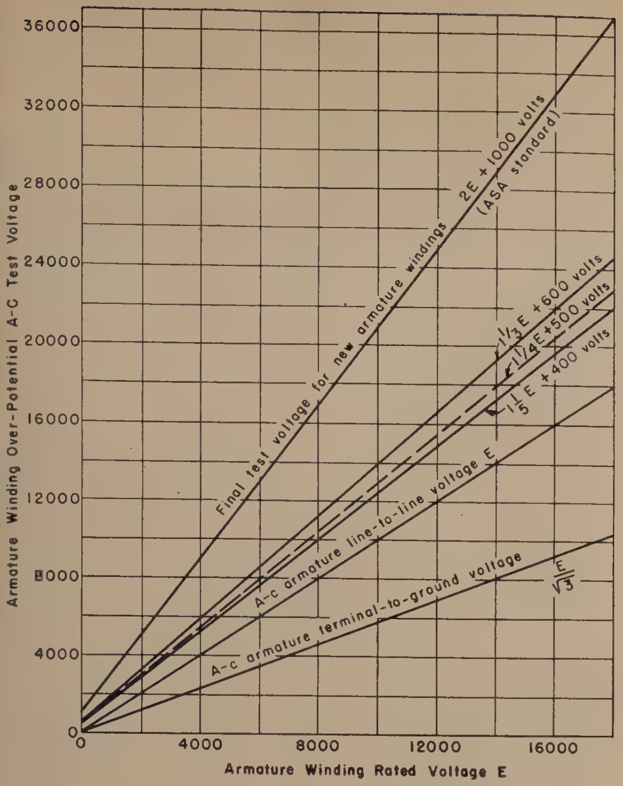

Fig. 3. A-c over-potential test for armature windings in service

Before installing replacement coils	$1\frac{1}{3}E+600$ volts
After installing replacement coils	$1\frac{1}{4}E+500$ volts
Suitability of winding for service	$1\frac{1}{5}E+400$ volts

On large Class B insulated armature winding, some users prefer a 10 percent higher test voltage than that indicated in these curves

at a voltage of $1\frac{1}{3}$E+600 volts or 19,000 volts. The charging kva will be 20 percent higher if the test voltage is increased 10 percent.

DIRECT-CURRENT OVER-POTENTIAL TEST

The test voltage data given so far apply to a-c testing. D-c is used in cable testing and it may be used to test rotating-machine windings. D-c testing equipment furnishes only the resistance leakage current whereas the a-c equipment must furnish a large capacitance current. Consequently, for testing large machines, the d-c testing equipment is much smaller and of lower cost than that required for a-c testing.

After a d-c test has been made, it is necessary to connect the winding terminals to ground for a long time, depending on atmospheric conditions, in order to completely discharge the winding. Large Class B insulated windings may retain a considerable electrostatic charge on a dry day for many hours. Unless the winding has been fully discharged, anyone coming in contact with the winding soon after testing may be fatally injured.

Repeated applications of direct voltage with reversed polarity produce severe insulation voltage gradients. Reversed-polarity voltage tests, therefore, should be avoided unless the winding has been completely discharged between the tests. Likewise the application of a reversed-polarity direct voltage to a winding immediately after a d-c over-potential test has been made, for the purpose of quickly reducing the winding electrostatic charge, is not recommended.

A-c and d-c over-potential tests produce somewhat different dielectric conditions in the winding. The a-c test produces a dielectric loss in the insulation and it may produce some corona. The d-c test produces a different type of corona and increased creepage stresses. The potential distribution on the winding end portion depends on resistance for the d-c test and mostly on capacitance for the a-c test. Hence on the winding end portion at small distances from the magnetic core, the d-c test will stress the insulation more than the a-c test. The a-c test is preferable for machine windings because it more nearly represents service conditions.

To puncture various types of undamaged insulation requires a d-c voltage of about 1.5 to 3 times the rms a-c voltage. This ratio does not apply to the voltage strength of various creepage surfaces of rotating machines in service. Thus a conservative d-c test voltage would be slightly above $\sqrt{2}$ times the a-c rms test voltage. With a ratio of the d-c test voltage to the a-c rms test voltage of approximately 1.5, the over-potential test voltages for armature windings in service, Table V, are suggested.

SUMMARY

Winding insulation is one of the important links of the rotating machine chain of service. Normal operation, proper maintenance, careful inspection, and appropriate testing all aid in obtaining long and dependable winding service.

TABLE III

TEST VOLTAGES FOR FIELD WINDINGS IN SERVICE

(After inspection, cleaning, and drying)

Machine	A-c (rms) Test Voltage
Synchronous-generator, 125-volt field	1000
Synchronous-generator, 250-volt field	1500
Synchronous-motor and Synchronous-converter fields	1500
D-c motor and generator fields	Same as armature winding for corresponding field voltage.

For some large machines, or machines built for special purposes, the test voltage may be somewhat higher than that indicated.

TABLE IV

APPROXIMATE CHARGING KVA OF 13,800-VOLT SYNCHRONOUS MACHINE ARMATURE WINDINGS WITH CLASS B INSULATION AT 25 C WITH 19,000 VOLTS (RMS) APPLIED AT 60 CYCLES

Winding Rated Kva	Approximate Charging Kva for Entire Winding at 60 Cycles				
	100 rpm	300 rpm	900 rpm	1800 rpm	3600 rpm
2,500	25	17	12	10	8
5,000	40	28	20	16	13
10,000	70	48	34	27	20
25,000	140	100	65	53	40
50,000	230	160	110	90	70
100,000	390	270	190	150	120

If only one phase of a three-phase winding is tested, the charging kva will be approximately 40 percent of these values.

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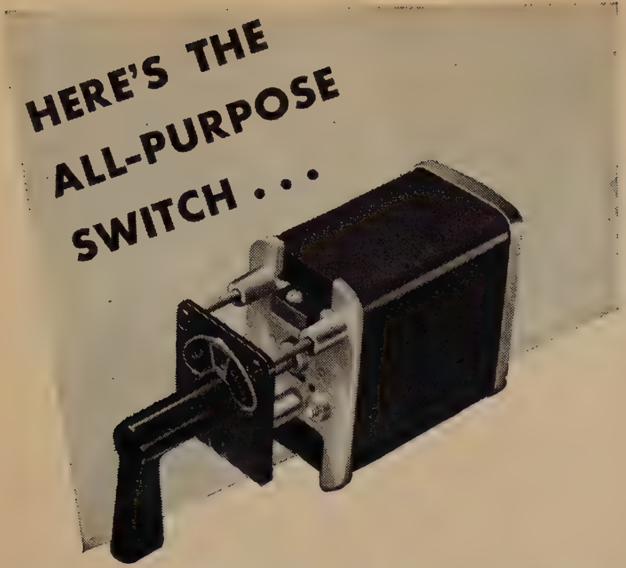

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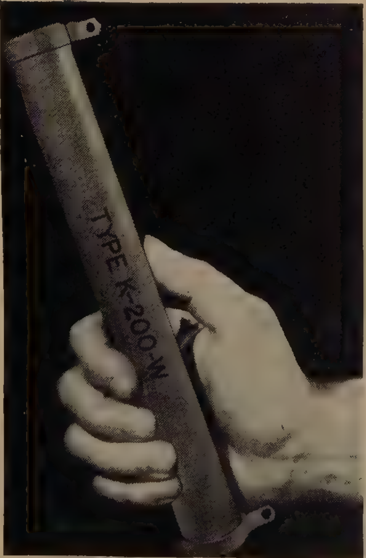

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MAINTENANCE OVER-POTENTIAL TESTS

(Continued from preceding page)

TABLE V

TEST VOLTAGES FOR ARMATURE WINDINGS IN SERVICE
(After inspection, cleaning, and drying)

Test	A-c (rms) Test Voltage	D-c Test Voltage
(1). Before Replacement Coils or Bars Are Installed	$1\frac{1}{3}E+600$	$2E+1000$
(2). After Replacement Coils or Bars Are Installed	$1\frac{1}{4}E+500$	$1\frac{7}{8}E+800$
(3). Suitability for Service	$1\frac{1}{5}E+400$	$1\frac{3}{4}E+600$

For large Class B insulated armature windings some users prefer a 10 percent higher test voltage than that given in this tabulation.

Before a service over-potential test is applied, the winding should be given a thorough visual inspection, cleaned if necessary, and its insulation resistance checked. If some replacement coils are to be installed, use the plan outlined in Tests (1) and (2), Table V. If it is desired to apply a moderate over-potential test to a winding to determine its suitability for continued service, use Test (3), Table V.

The frequency of over-potential testing depends on service conditions. Some operators find it expedient to apply a maintenance over-potential test every one or two years to coincide with the overhauling program.

Testing equipment should have ample capacity, adequate voltage stability, and a voltage which is relatively free from harmonics. If a d-c test is used, it is important to ground the winding for a sufficient time to completely remove the electrostatic charge.

The recommended practice for maintenance over-potential testing of machine windings, outlined in this article, should aid in standardizing the test for windings in service on the same basis as the standard proof test for new windings.

REFERENCES

(1)"Recommended Practice for Testing Insulation Resistance of Rotating Machinery." *AIEE Publication No. 43*, April 1950.
(2)"Capacitance of Synchronous-machine Armature Windings Determined for High-potential Test," by R. W. Wieseman, GENERAL ELECTRIC REVIEW, vol. 50, July 1947, p. 26.

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PROGRESS IN DESIGN OF STEAM TURBINES FOR ELECTRIC POWER GENERATION IN THE UNITED STATES

Standardization; analysis of shipments; classification of current turbine designs; high-pressure turbine shells; rotors; buckets and diaphragms; valves and governing mechanism; summary of the progress and development

By EDWIN E. PARKER
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Edwin E Parker

DURING and following the war both the users and manufacturers of steam turbines for electric power generation in the United States have been continuously challenged by the rapid growth of the electric power load requiring a large increase of generating capacity.

Of the generating capacity currently being added, that provided by steam has comprised approximately 80 percent of the total. It might be assumed that such a condition would retard design progress in the interest of increased production. This is not the case, however, as the same period has been one of rapid progress in the development of the steam turbine and the entire steam plant. Notable advances have been made in the (1) development of much larger 3600-rpm units, (2) manufacture of turbines for initial temperature as high as 1050 F, (3) improved designs and extensive production of turbines for 950 and 1000 F initial temperature, and (4) wide application of the resuperheat cycle at today's pressure and temperature conditions.

The progress in development of steam-electric generating equipment has permitted continued reduction in the national average station heat rate, and is resulting in the construction of some new steam units with over-all heat rates below 10,000 Btu per kw-hr—the best with over-all thermal efficiency approaching 37 percent at the most favorable load.(1) In American steam power-plant practice, heat rates and efficiencies are based on the higher heating value of the fuel.

This article will be limited to consideration of steam turbines of 10,000 kw and larger for central-station service, and will describe features of modern steam turbines manufactured by the author's Company in the United States. While the article deals exclusively with steam turbines, it is important to recognize that a corresponding advance has been both necessary and accomplished in the design and manufacture of large 3600-rpm two-pole turbine-generators.

STANDARDIZATION

The establishment of a standard(2) for six turbine sizes ranging from 11,500 to 60,000 kw by a joint AIEE–ASME committee on Preferred Standard Turbines and Generators has been of assistance in meeting the large demand for steam-electric generating equipment.

These standards cover turbines and generators for capacities and steam conditions which were well developed before the standard was established. No attempt was made to standardize either the larger units, the turbines for advanced steam conditions, or the resuperheat cycle. Thus progress to advanced designs has not been impeded, yet benefit to production has been achieved by standardization over a range well established by experience. A typical heater arrangement and heat balance for a 40,000-kw preferred standard turbine is shown schematically in FIG. 1.

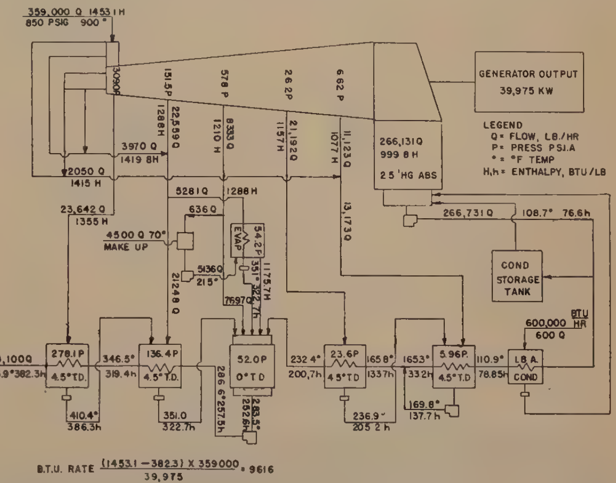


Fig. 1. Typical arrangement of heaters and heat balance for AIEE–ASME 40,000-kw Preferrred Standard turbine-generator

ANALYSIS OF SHIPMENTS: 1947 THROUGH 1950

To assist in studying the trends in initial pressure, temperature, size, and speed of turbines of 10,000 kw and larger for central-station service, the shipments by the author's Company for the four-year period 1947 to 1950 inclusive have been analyzed and included in Table I. This table is based on actual shipments plus the scheduled shipments through 1950. It was possible to do this as the manufacturing schedule is completely filled beyond 1950.

This article was presented as a paper at the Fourth World Power Conference, July 1950, London (England).

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

(1) Numbered references are listed at the end of the article.

Table I shows that by 1950 the most widely used temperatures will increase from 900 to 950 deg, and 1000 and 1050 deg temperatures will account for more than 25 percent of the total production. The trend in pressure is away from the 850 psig level and toward the 1250 to 1450 level.

Both 1800-rpm and 3600-rpm turbines have their place in turbine production during this four-year period. The 1800-rpm turbines find application where large exhausts are required, such as for large units with low-temperature condenser water, while the 3600-rpm turbines find their best range of application for higher-pressure higher-temperature installations requiring more moderate exhaust areas.

TABLE I

ANALYSIS OF GENERAL ELECTRIC COMPANY SHIPMENTS 1947–1950 OF CENTRAL-STATION TURBINES IN SIZES 10,000-KW AND LARGER

Percent of Total Kw Capacity Shipped (Based on Nameplate Rating)

TEMPERATURE	1947	1948	1949	1950
1001–1050	0	3.8	17.3	12.0
951–1000	11.3	3.8	2.9	16.5
901–950	16.7	40.2	33.4	42.1
826–900	57.5	39.6	41.0	25.3
751–825	7.7	4.4	3.4	3.2
750 and below	6.8	8.2	2.0	.9
PRESSURE				
1801–2000	0	0	13.7	7.5
1451–1800	4.6	3.8	3.7	4.5
1251–1450	2.2	11.3	13.8	30.8
851–1250	19.1	24.7	20.7	29.6
651–850	49.9	47.2	42.7	24.1
451–650	14.7	5.1	4.0	3.2
450 and below	9.5	7.9	1.4	.3
SPEED				
1800	11.8	22.1	34.0	15.7
3600	80.7	74.1	66.0	82.4
Special	7.5	3.8	0	1.9
RESUPERHEAT	0	0	13.7	19.2
NONREHEAT	100	100.0	86.3	80.8
CONDENSING	95.5	100.0	98.7	98.2
NONCONDENSING	4.5	0	1.3	1.8
AVG. SIZE KW	35,565	44,338	48,149	53,088

The table also illustrates the growing use of the resuperheat cycle in the United States with the proportion of resuperheat turbines becoming considerable for 1950. Only a very small part of the total capacity being installed over this four-year period is for noncondensing service, which includes topping of existing low-pressure plants. In addition to the trends shown in Table I, an analysis of the initial temperature trends over the years indicates that on an average the highest initial temperature being used in any plant increases at the rate of about 12 F per year. If progress continues at this rate during the next ten years, initial temperatures for steam plants of 1150 deg may be expected by 1960. Progression has not been smooth, however, and such a prediction may be accelerated or delayed by many factors.

CLASSIFICATION OF CURRENT TURBINE DESIGNS

The more widely used types of condensing turbines for central-station service are listed in Table II. Also given are the highest steam conditions and maximum capacity for these turbines built by or on order with the author's Company.

The maximum capacity and highest steam conditions do not necessarily exist on the same turbine, but a turbine for both the listed capacity and steam conditions can be manufactured if required.

In addition to the types shown in Table II, there has been some production of cross-compound, tandem-

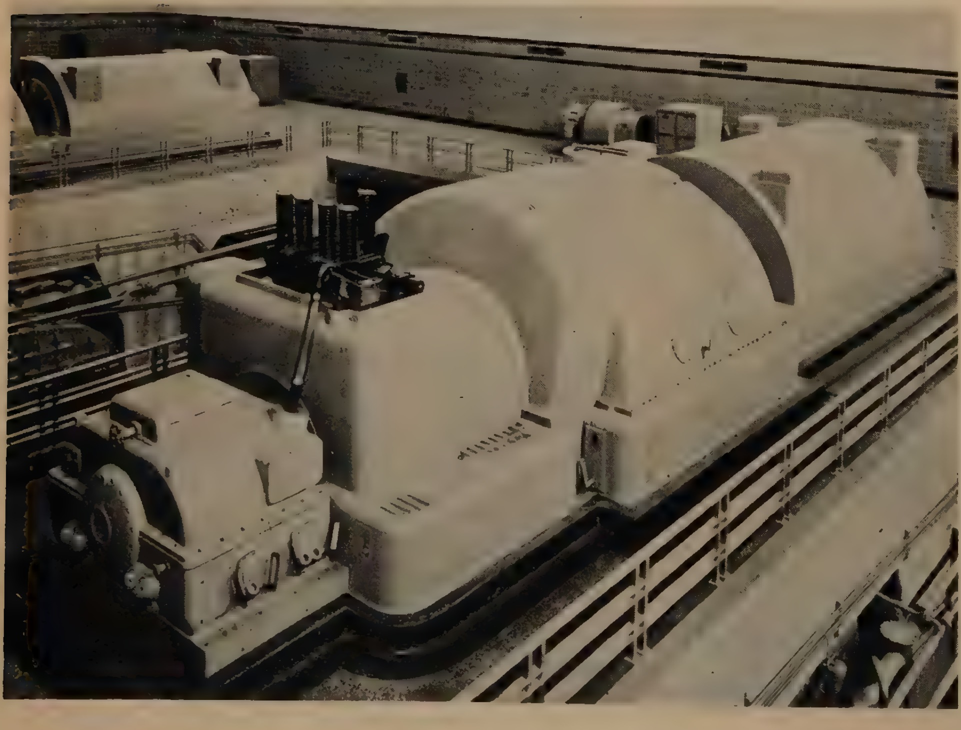


Fig. 2. Station view of modern 50,000-kw 3600-rpm tandem-compound double-flow turbine-generator

ompound, single-flow, and noncondensing turbines. There have also been built or are on order a number of ingle-cylinder and tandem-compound 3000-rpm turines to drive 50-cycle generators for installation outide the United States.

FIG. 2 is a typical installation showing the appearance esign of a modern turbine-generator unit.

600-RPM CONDENSING TURBINES

Following the war, larger tandem-compound 3600-pm condensing turbines with capacities in the order of 00,000 kw were developed. Where the power system s large enough to justify units with capacities of 100,00 kw and above, the single unit has proved to be iore economical than two or more smaller units of he same total capacity. Therefore, these larger 3600-pm turbines have found a wide field of application.

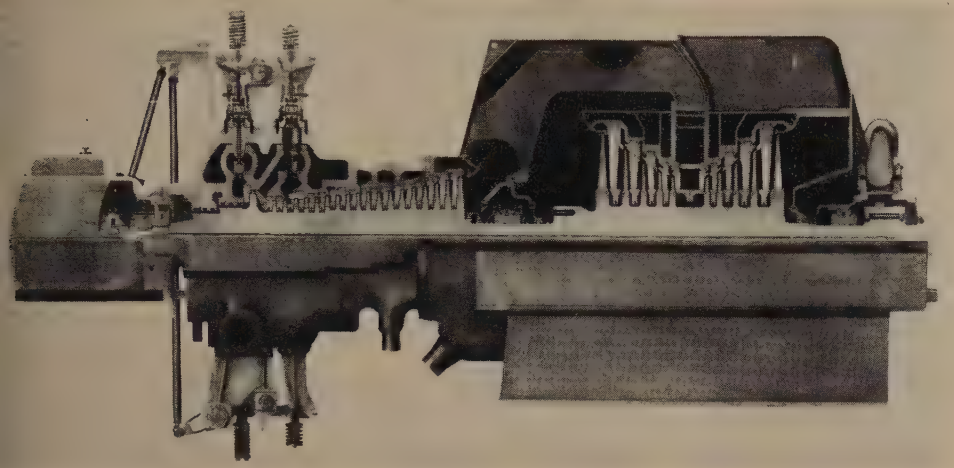


Fig. 3. 100,000-kw 3600-rpm 24-stage tandem-compound double-flow turbine

To produce those turbines, it was necessary to evelop a last-stage bucket having more annulus area han those already available. A bucket having a 23-in. ane section was developed which provided an exhaust nnulus area approximately 30 percent greater than as previously available.

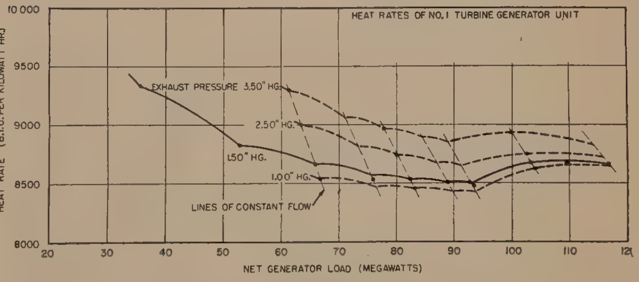
The first large turbine using those buckets went into ommercial service in December 1947. A cross-section f it is shown in FIG. 3. It has a rating of 100,000 kw at steam conditions of 1250 psig, 1000 F, and 1½ in. Hg absolute back pressure. The turbine length is 32 ft 8 in., and the rotor weight is 51,000 lb. Several turbines of this design have been placed in service. One was recently tested co-operatively by the manufacturer and the owner.⁽³⁾ The results of this Essex test are shown in FIG. 4. This test shows that at the best point (load 93,000 kw and exhaust pressure 1½ in. Hg absolute) the turbine heat rate was 8498 Btu per kw-hr. A unit of similar design and rating, except for operation at 3000 rpm, is installed in the Gennevillier Station in Paris (France).

TABLE II

CONDENSING TURBINES FOR ELECTRIC POWER GENERATION

TYPE	SPEED (rpm)	Highest Steam Conditions and Capacity Built or on Order: Steam Conditions (psig)	(°F)	Max Cap (kw)
ngle-Casing	3600	1350	1000	37,500
andem-Compound ouble-Flow	3600	1650	1000	111,000
andem-Compound riple-Flow	3600	2000	1050	153,000
andem-Compound ouble-Flow	1800	1450	1000	170,000
ngle-Casing	1800	1250	950	111,111

Fig. 4. Heat rates from station tests on 100,000-kw 3600-rpm turbine



Extensive tests were also made to determine the mechanical performance of the Essex turbine.⁽⁴⁾ These tests furnished data useful for establishing starting and loading cycles, and permissible rates of change of throttle steam temperature. They also indicated that the turbine can be started and synchronized conservatively in an hour's time or less, depending upon the temperature of the turbine at the start. The limits on the loading and unloading rates were not determined by the test as other factors were limiting; however, they were shown to be in excess of values normally employed.⁽⁵⁾

A 3600-rpm tandem-compound triple-flow turbine has been developed for either lower back-pressure conditions or larger sizes than the double-flow turbine previously described. The first turbine of this type manufactured was for 1050 F initial temperature.⁽⁶⁾ It is shown in FIG. 5 and consists of a high-pressure single-flow and a double-flow low-pressure section. This turbine, like all 3600-rpm tandem-compound turbines of this manufacturer, employs an internal crossover which

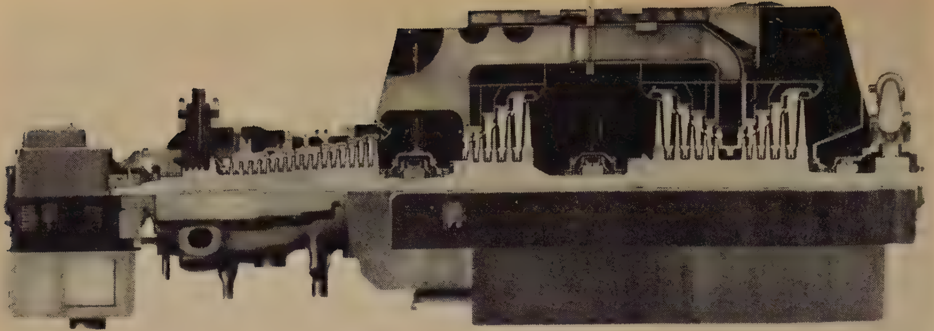


Fig. 5. 100,000-kw 3600-rpm 23-stage tandem-compound triple-flow turbine

reduces the length for either double- or triple-flow and simplifies the foundation arrangement, using a foundation construction similar to that of a single-casing turbine. It eliminates the requirement of a cross member in the foundation to support the casing between the high- and low-pressure sections. This turbine employs 23-in. last-stage buckets and hence provides 50 percent more annulus in the last stage than is provided by the double-flow turbine. The triple-flow exhaust increases the turbine length by approximately seven feet. The combined weight of the high- and the two low-pressure rotors is 68,800 lb.

3600-RPM NONCONDENSING TURBINES

The requirements for noncondensing turbines to top existing low-pressure equipment have decreased in the past few years, although there have been several important installations of this type turbine. FIG. 6 illustrates a recent 50,000-kw noncondensing turbine built for steam conditions of 1600 psig, 950 F, with exhaust at 200 psig. It has double-shell construction with the space between the inner and outer shells operating at about 520 psig at maximum load. When an efficiency test on this unit was conducted in the owner's plant, the unit was found to be better than guaranteed by approximately 1.6 percent. This turbine has an over-all length of 20 ft with a rotor weight of 16,000 lb. Noncondensing 3600-rpm turbines have been built with capacities up to 60,000 kw at the 1200-psi pressure level, and with flow capacities of approximately 2,000,000 lb per hr at the 900-psi 950 F level.

1800-RPM CONDENSING TURBINES

Condensing 1800-rpm turbines meet application requirements where large-capacity turbines are desired in locations with cold cooling water, because of the large last-stage annulus area that can be provided. Two types of 1800-rpm turbines are currently in production,

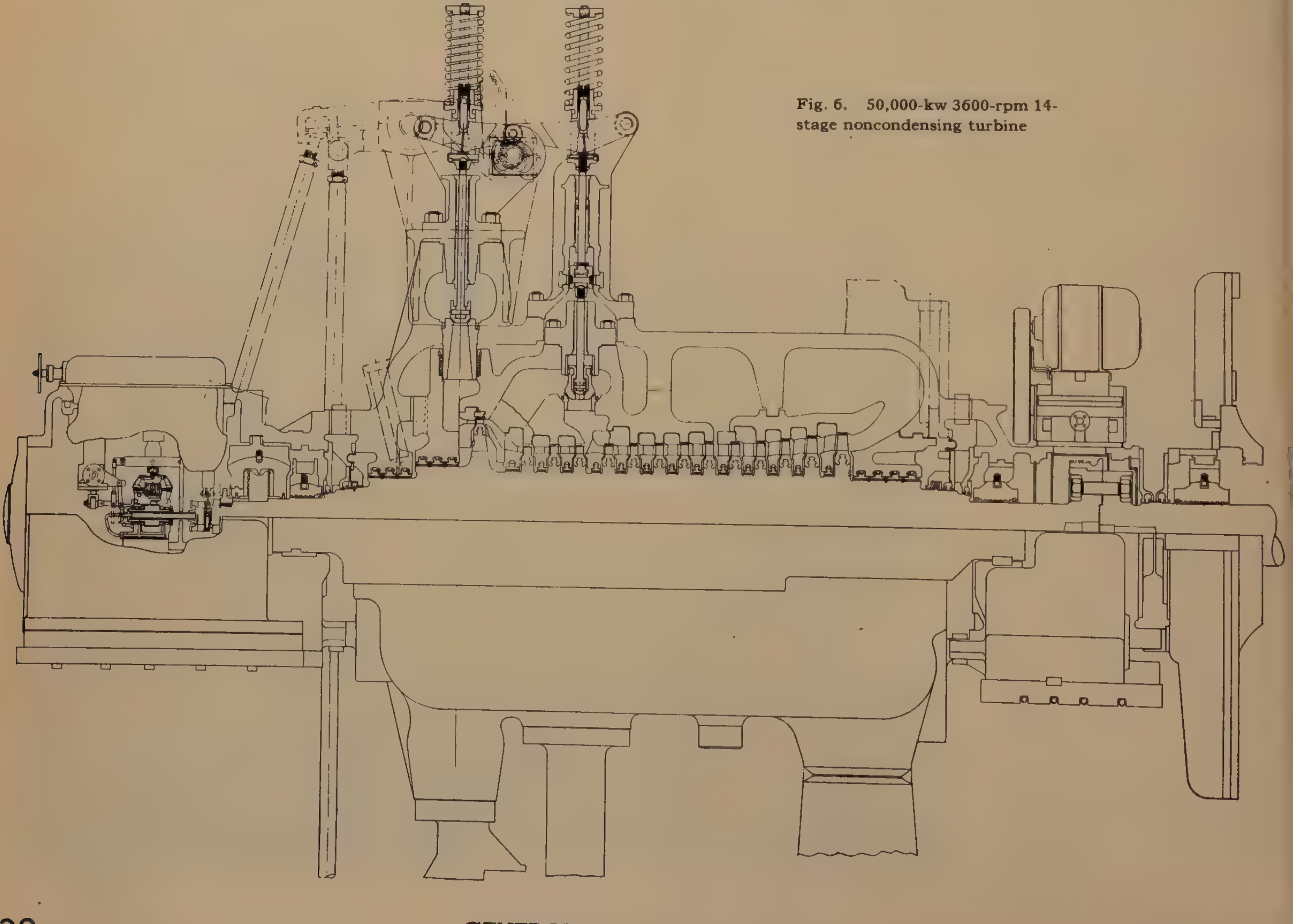


Fig. 6. 50,000-kw 3600-rpm 14-stage noncondensing turbine

one a single-casing single-flow and the other a tandem-compound double-flow. Special types such as tandem-compound single-flow and single-casing double-flow have been produced, but will not be considered in this article as these have limited application.

The 1800-rpm single-casing single-flow turbine is represented in FIG. 7. This is a 17-stage turbine rated 100,000 kw at 1300 psig, 950 F, and 1 in. Hg absolute back pressure, with a maximum capacity of 110,000 kw. It utilizes 35-in. buckets, resulting in a last-stage annulus area of 83.8 sq ft. The turbine has an over-all length of 31 ft and a rotor weight of 85,000 lb.

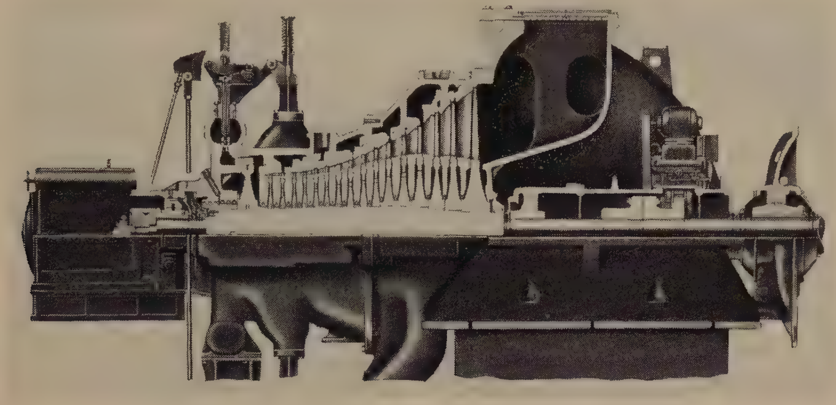


Fig. 7. 100,000-kw 1800-rpm 17-stage single-flow turbine

FIG. 8 represents the type of 1800-rpm tandem-compound double-flow turbine now in production. This design is being used in both straight-condensing service and in the low-pressure section of cross-compound resuperheat turbines. The cross-section shown in FIG. 8 is for a turbine rated 150,000 kw with 165,000 kw maximum capacity at steam conditions of 1250 psig, 925 F, 1 in. Hg absolute back pressure. It has an over-all length of 47 ft 11 in. and combined rotor weight of 163,500 lb. Turbines of this general construction are being produced for ratings of 100,000 and 125,000 kw at initial temperatures as high as 1000 F.

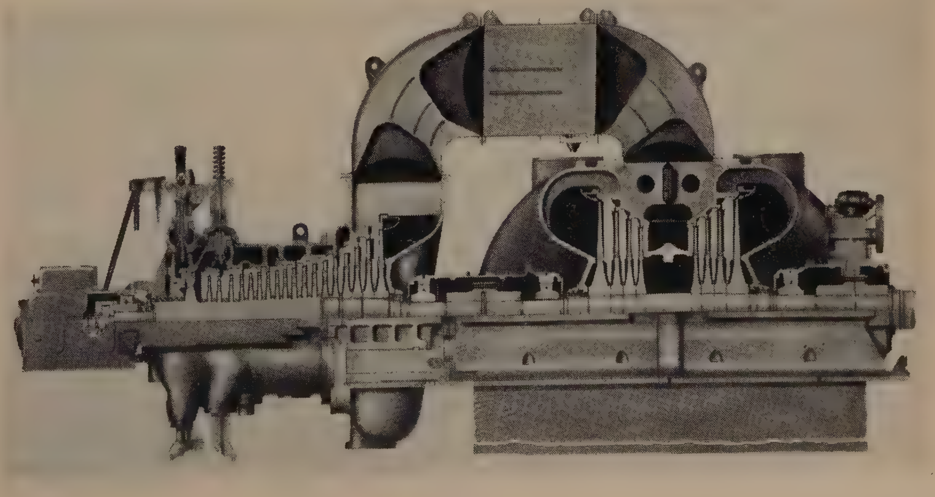
TURBINES FOR RESUPERHEAT CYCLE

As shown in Table I, a considerable percentage of the capacity being shipped in 1949 and 1950 is for the resuperheat cycle. This renewed interest⁽⁷⁾ in the resuperheat cycle has been caused by several factors, the major one being the increased cost of fuel. Another is that 1000 F appears to be close to the limit for the use of today's ferritic-type steel alloys; progression appreciably above 1000 F requires the use of expensive stainless steel alloys of the austenitic type. Roughly, the 4½ to 5 percent gain⁽⁸⁾ resulting from resuperheating at the 1000 F level equals the gain to be obtained from a nonreheat installation at initial temperatures of 1150 to 1200 F. Still another factor for the acceptance of the resuperheat cycle in the United States has been the excellent availability of both modern boilers and turbine-generators. This has led to many installations using only one boiler and one turbine to save capital investment and to simplify operation. A unit boiler-and-turbine installation is ideal for simplifying the operation of a resuperheat plant, largely overcoming the objection of operators to the complication of the earlier resuperheat installations.

Turbines for the resuperheat cycle are currently being produced in ratings from 50,000 to 125,000 kw. The steam conditions for resuperheat turbines produced in 1949 and 1950 are shown in Table III.

A recent development in the design of resuperheat turbines that reduces the cost and simplifies the installation is shown in FIG. 9. High-pressure steam enters the turbine shell at the midsection, traveling forward

Fig. 8. 150,000-kw 1800-rpm 23-stage tandem-compound double-flow turbine



it is exhausted to the reheater at the front end of the shell. After passing through the reheater, the steam again enters the shell at the midsection. From this point it flows through an intermediate section and then in a conventional manner through a double-flow low-pressure section. This arrangement for admitting the initial and resuperheated steam at points adjacent to one another in the midsection of the high-pressure shell confines the high temperature to one portion of the shell and eliminates any large temperature gradients in the turbine parts.

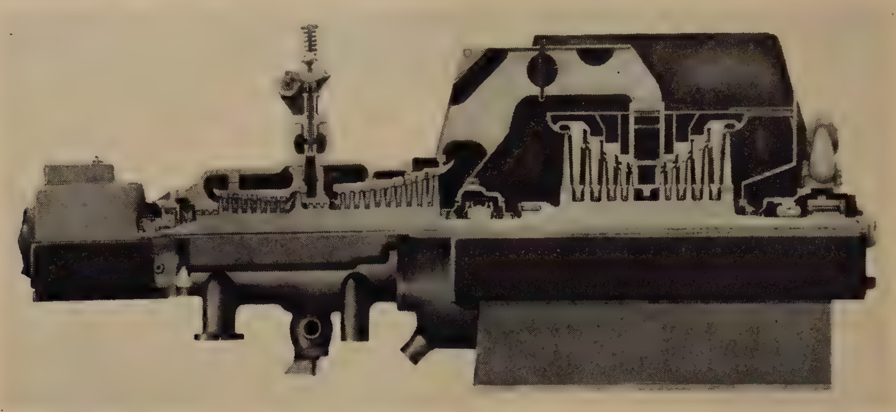


Fig. 9. 80,000-kw 3600-rpm 23-stage tandem-compound double-flow turbine for the resuperheat cycle

TABLE III

PERCENTAGE OF TOTAL RESUPERHEAT TURBINE CAPACITY FOR SHIPMENT IN 1949 AND 1950
Based on Nameplate Rating

Steam Conditions			1949	1950
Press. (psig)	Initial Temp. (°F)	Resuperheat Temp. (°F)	Per cent	Per cent
2000	1050	1000	100	33.8
1450	1000	1000	0	52.7
1250	950	950	0	13.5

Externally that resuperheat turbine closely resembles a nonreheat turbine of the same capacity and is being produced with appropriate exhaust areas in ratings of 50,000, 60,000, and 80,000 kw. The 80,000-kw size is provided with two rows of last-stage buckets having 23-inch-long vane section. When designed for the same maximum capacity, it has an over-all length of only 1.5 in. greater than the equivalent nonreheat turbine that was shown in Fig. 3.

A three-casing tandem-compound triple-flow turbine design, as shown in Fig. 10, has been developed for 3600-rpm resuperheat turbines with ratings in excess of 80,000 kw. The first application of this 23-stage unit is for a rating of 110,000 kw, with a maximum capacity of 121,000 kw at steam conditions of 1800 psig, 1000 F initial, reheat to 1000 F, and 1 in. Hg absolute back pressure. Provision has been so made that the high-pressure section can be opened and the rotor removed without dismantling the intermediate or low-pressure section, or vice versa. The length of the unit shown in Fig. 10 is 44 ft, and the rotor weight is 68,200 lb.

A number of cross-compound turbines(9) are being produced for the resuperheat cycle. These are 3600-rpm high-pressure turbines and tandem-compound double-flow 1800-rpm low-pressure turbines. They will operate at 2000 psig and 1050 F initial with resuperheat to 1000 F, and have a rated capacity of 125,000 kw and a maximum capacity of 150,000 kw.

These turbines and the associated equipment comprise installations having the highest thermal efficiency of any steam-electric units built or under construction.

All recent resuperheat turbines manufactured by the author's Company have been provided with water-spray nozzles in the cross-over between the intermediate- and low-pressure sections. Most of these are automatically controlled to prevent overheating of the low-pressure section and the exhaust hood when operating at no-load or very light loads. Preliminary experience with this arrangement of cooling by water sprays indicates that, at no load, it reduces the heating of the exhaust to a temperature less than usually encountered on an equivalent nonreheat turbine.

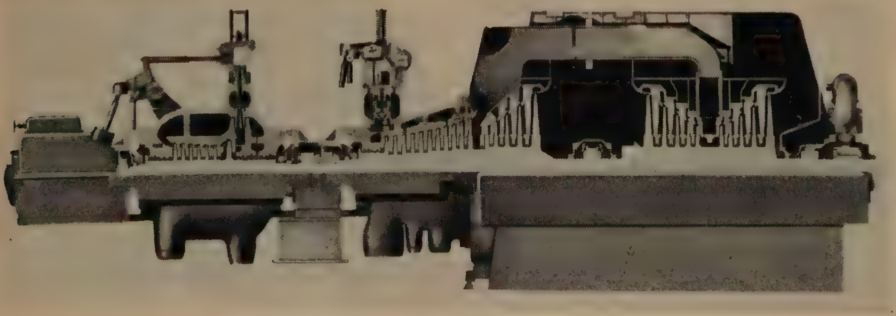


Fig. 10. 110,000-kw 3600-rpm 23-stage tandem-compound triple-flow turbine for the resuperheat cycle

To protect the reheater against overheating upon sudden loss of load, the turbine control valves and emergency stop valve have been provided with switches which are integrated with the boiler control to reduce the firing rate or shut it off completely, depending upon the situation.

HIGH-PRESSURE TURBINE SHELLS

The record on high-pressure turbine shells with respect to design, manufacturing, materials, and service has been one of continued improvement. With the advent of high pressures and temperatures, the double-shell construction(10) was developed, and it has been widely applied with outstanding success. By improvement in materials and design techniques, the use of single-shell construction has been applied successfully at higher and higher temperatures and pressures until it is now used in some designs for conditions as high as 1250 psig and 1000 F.

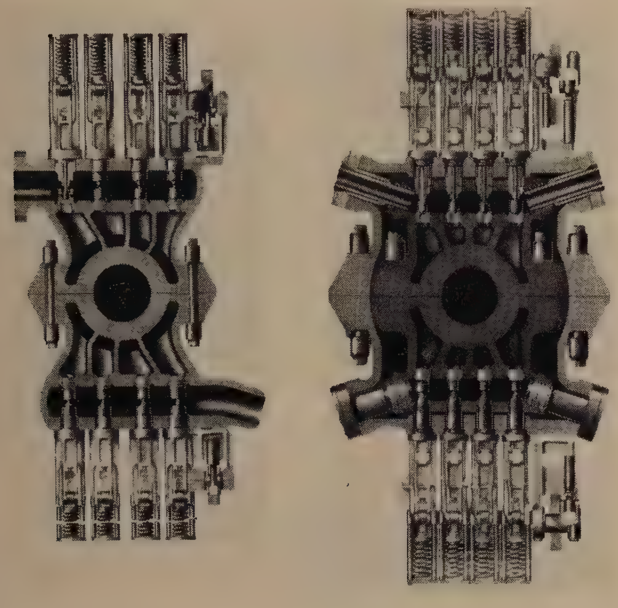

A B

Fig. 11. Transverse cross section of turbine shells through steam chest
Section *A*: Single-shell construction
Section *B*: Double-shell construction

It is characteristic of all large turbines built by the author's Company for high-temperature operation to have admission of throttle steam in both the upper- and lower-half turbine shells. On most turbines this is accomplished by mounting (governor-operated) control valves on both the upper- and lower-half shells. An alternate practice, infrequently applied, is the use of a separate steam chest containing the control valves as was illustrated in Fig. 5. The symmetry plus the uniform heating assures the best dimensional stability of the high-pressure end of the turbine. Fig. 11 shows transverse cross sections through the steam chests of two turbine shells; section *A* illustrates the construction for single-shell design, and *B* the construction for double-shell design. In section *B* the steam chest is shown on the inner shell. This arrangement is used for the highest steam conditions now in use. For intermediate conditions, the double-shell construction is often used with the steam chest located on the outer shell. These cross sections also illustrate the configuration and the bolting of horizontal joints.

Fig. 12 is a photographic illustration of double-shell construction; the inner shell is assembled and the top-half outer shell is removed. This is the type of double-shell construction shown in section *B*, Fig. 11.

To preclude excessive plastic deformation with time, and to provide an adequate factor of safety against rupture after a long period of service, shells for high steam temperatures and pressures must have great strength through the front section. The design of valve gears materially affects the strength which can be readily designed into this portion of the shell surrounding the steam chest and nozzle passages. Individual cam-operated valves are well adapted to the design of high-strength shells. Moreover, generous ligaments can be provided both at the top and bottom surfaces of the steam chest between the valves to resist tension and bending stresses arising from the internal pressure. The strength of the front portion of the shell is also increased by spherical contours and carrying heavy horizontal joint sections across the packing opening.

Shown in Fig. 13 is a shell consisting of a valve chest which has been cast separate from the main portion of the shell. After proper preparation of both castings, the valve chest is welded to the shell. This not only permits improved provisions for casting but also allows for excellent cleaning, better and more thorough inspection, and easier repair of any casting defects. This construction is being used extensively, and it results in both improved quality and lower cost.

Shells for high-temperature service up to and including 1000 F have been produced from low-alloy ferritic steels. These have been molybdenum and molybdenum-vanadium alloys, the molybdenum-vanadium alloys being used at the higher temperatures. Graphitization has not been a factor with these cast-shell materials, but the trend is to add chromium to the molybdenum and molybdenum-vanadium alloys. Extension of the

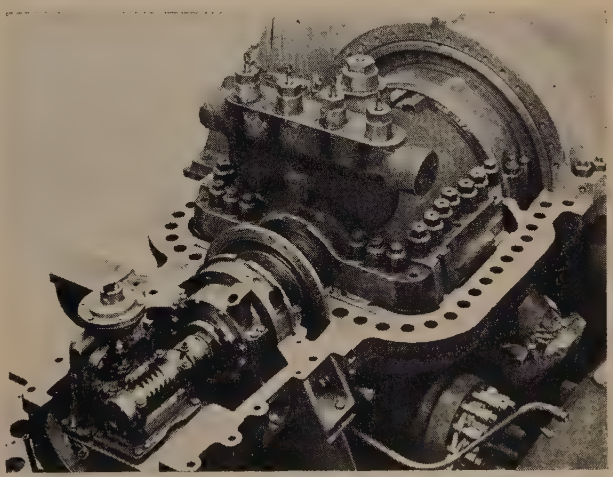


Fig. 12. Turbine showing double-shell construction, with top half of outer shell removed

use of a chromium-molybdenum-vanadium alloy for some designs is now being made to the 1050 F level. At this level a number of turbines have been produced using cast 18-8 type austenitic alloy which has been stabilized with columbium and strengthened by the addition of molybdenum. Where this more expensive stainless-steel alloy has been used, double-shell construction has been utilized, and the expensive alloy confined to the forward portion of the inner shell. Fig. 14 shows the dovetail arrangement by which the austenitic forward portion is dovetailed to a low-alloy-steel rear section.

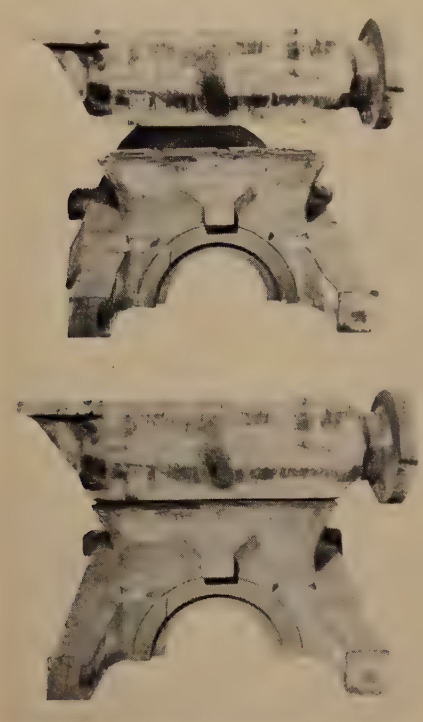


Fig. 13. **Cast turbine shell and steam chest before welding**

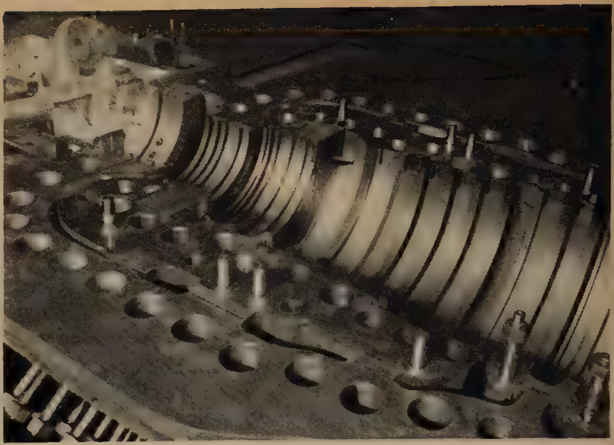


Fig. 14. **Lower-half turbine shell showing stainless-steel forward portion of inner shell dovetailed to low-alloy-steel rear section**

Notwithstanding the advance to higher temperature and pressure levels, the performance of high-pressure turbine shells with respect to dimensional stability, absence of flange leakage, and absence of cracks has improved to a point where troubles of this nature are almost nonexistent on modern turbines. This is the result of both the design of the shells as previously described and the improvement in inspection and repair techniques during manufacture. Every high-pressure turbine shell is carefully examined by the magnetic-particle method. Defects are removed and magnetic tests repeated; the process is continued until it is established that the defect is completely eliminated. The castings are then repair-welded under accurately controlled conditions and, finally, magnetically tested for soundness of the weld repair before final heat treatment. X-ray also is used extensively in examining production castings as a supplement to the magnetic test.

ROTORS

Rotors for turbines of 15,000 kw and above manufactured by the author's Company for operation at 3000 rpm or 3600 rpm are made from solid-steel forgings. Recently this practice has been extended to a portion of the high-pressure rotor of 1800-rpm tandem-compound turbines. This permits application of these 1800-rpm turbines at higher initial temperature levels. A cross section of such a unit was shown in Fig. 8.

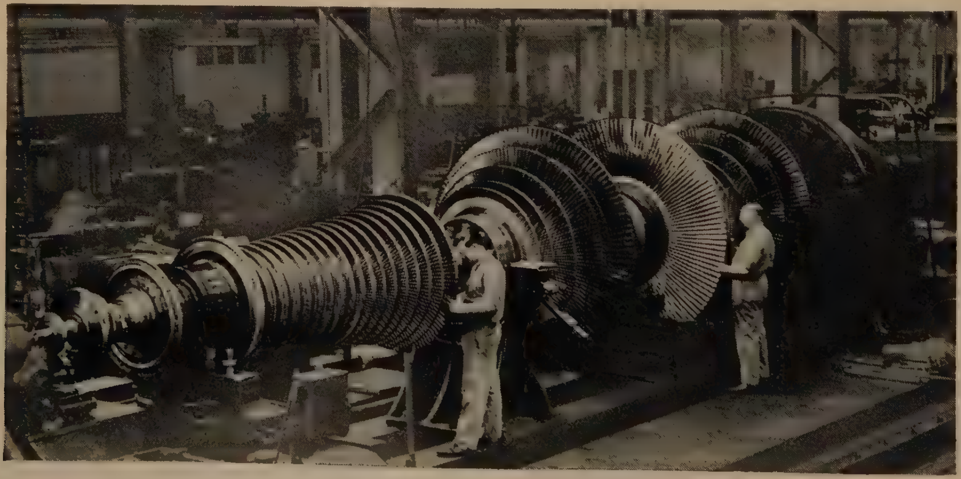


Fig. 15. **Turbine rotor for 100,000-kw 3600-rpm tandem-compound triple-flow turbine**

Fig. 15 is a photograph of the turbine rotor for the

100,000-kw 3600-rpm tandem-compound triple-flow turbine that was shown in Fig. 5. This rotor consists of three sections—one high and two low—each of which was made from a solid forging. These three rotors plus the main generator rotor plus a house generator are joined into one integral unit by solid couplings. Flexible couplings are not used on modern turbines except for the driving of such auxiliaries as exciters and oil pumps. To date, even on the highest-temperature turbines, low-alloy ferritic-steel rotor materials have been used. For the highest-temperature units this rotor material is a chromium-molybdenum-vanadium alloy. The principal alloy element in the rotor material for lower-temperature applications is molybdenum.

In 1947, the practice of ultrasonic testing of every turbine and generator rotor was started. Previously, ultrasonic testing was used only in special cases to supplement other testing methods. This procedure has disclosed defects which would not have been shown by other tests; thus modification of certain steel-making practices has been required. As a consequence, the quality of forgings is now more uniform.

All high-pressure turbine-rotor forgings are given two heat-stabilization tests; one before acceptance from the steel maker, and one following all machining of the turbine rotor except bucket dovetailing.(11) This heat test serves to insure that the turbine will operate satisfactorily under varying load conditions when placed in service.

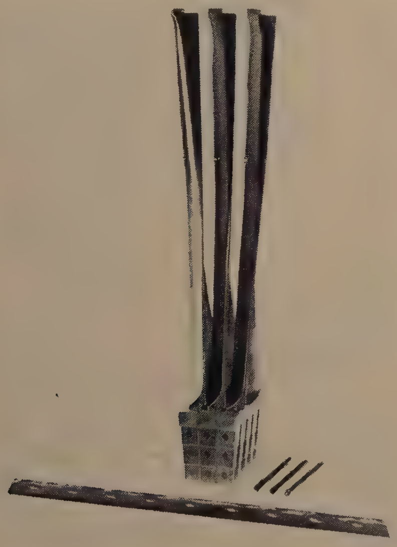


Fig. 16. Last-stage 23-in. buckets for operation at 3600 rpm

Associated with the design of rotors is the problem of properly proportioning the critical speeds of the individual spans to obtain proper transverse criticals for the combined rotor. Progress has been made in understanding the effect of foundation flexibility on transverse multispan criticals. This, together with improved calculation methods, is permitting design of multispan transverse criticals to avoid criticals at or near running speed. Many field tests with the units on their own foundations have been made to verify the accuracy of the design calculations. Torsional criticals of solidly coupled turbine and generator rotors are proportioned to limit the stresses which occur under generator short-circuit conditions.

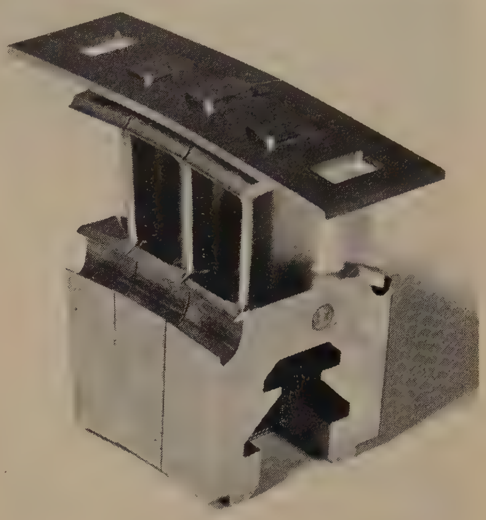


Fig. 17. First-stage buckets for large 3600-rpm turbines

BUCKETS AND DIAPHRAGMS

The author's Company uses the terminology of buckets to designate the moving steam-path part. The diaphragm is the entire stationary assembly including the nozzle partitions which direct steam through the moving buckets.

The limiting-stress conditions for the buckets of any particular turbine occur in the first and last stages. These stresses are not related because they result from steam loading in the first stage at light load and centrifugal loading in the last stage. A 23-in. bucket for last-stage application is shown in Fig. 16. This bucket is for operation at 3600 rpm with a pitch diameter of 65.5 in. and a tip velocity of 1395 ft per sec. On the back of the entrance edge is carried a Stellite erosion shield which extends 8.5 in. inward from the tip. The bucket is attached to the rotor by a finger-type dovetail. A number of rows of these buckets are in operation, and a similar bucket with a 72.5-in. pitch diameter is in operation at 3000 rpm.

To carry the high steam loads which occur on the first-stage buckets of large high-speed turbines at partial admission, the construction shown in Fig. 17 was developed. This consists of an integral bucket cover to resist the steam loading, together with a standard-type cover to connect a group of buckets. This construction is referred to as "double cover." It has successfully met the service requirements on all first stages of condensing and noncondensing turbines built by the author's Company.

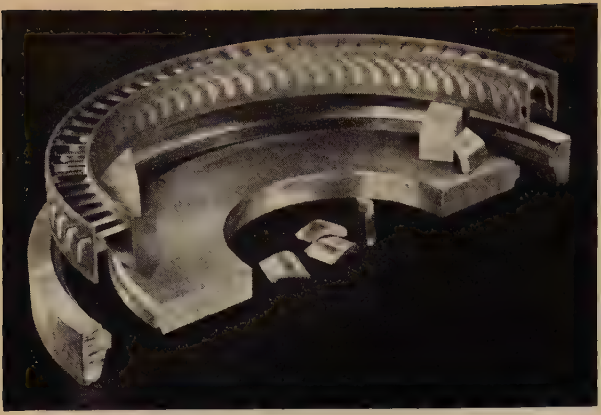


Fig. 18. Components of a fabricated diaphragm before welding

The shapes of nozzle partitions used both in welded and cast diaphragms have been improved for better efficiency. Other diaphragm improvements include the use of Monel inserts in both the diaphragm vertical steam joint and matching shell ledge for all diaphragms in the wet region. This Monel-to-Monel steam joint greatly reduces the erosion of the diaphragm and shell ledges. FIG. 18 illustrates the components of a welded diaphragm before welding the nozzle section to the ring and web.

Leaded-bronze material is being used on the face of the diaphragm opposite the bucket-root deflector and bucket cover, as shown in FIG. 19. This provides a soft material with good rubbing characteristics which permits operation of the high-pressure stages at closer clearances than could otherwise be maintained. If under transient load conditions the bucket root deflector or cover contacts this material, a groove is quickly worn away without increase of the effective leakage area around the bucket.

VALVES AND GOVERNING MECHANISM

For starting of the unit and operating at normal speed, the steam flow to the turbine is regulated by the control valves. These are positioned by the speed-governing mechanism except during starting, when they are positioned by the load-limit and starting handwheel (FIG. 20). The emergency-stop valve operated by the emergency governor is never used to control speed. It is wide open during all operation of the turbine. A seal is provided on the stem to prevent leakage of steam along the stem when the valve is open. This seal guards against the possible deposit of boiler compound which might cause the valve to be inoperative when required in an emergency. The construction of the emergency-stop valve with stem seal is shown in FIG. 21.

The control valves are operated in proper sequence by a cam shaft driven by the main hydraulic cylinder. For moderate and high steam temperatures, use is made

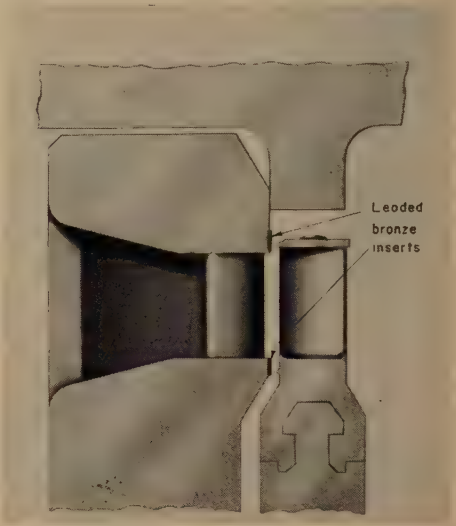


Fig. 19. Turbine nozzle and bucket assembly showing use of leaded-bronze inserts opposite bucket-root deflector and bucket cover

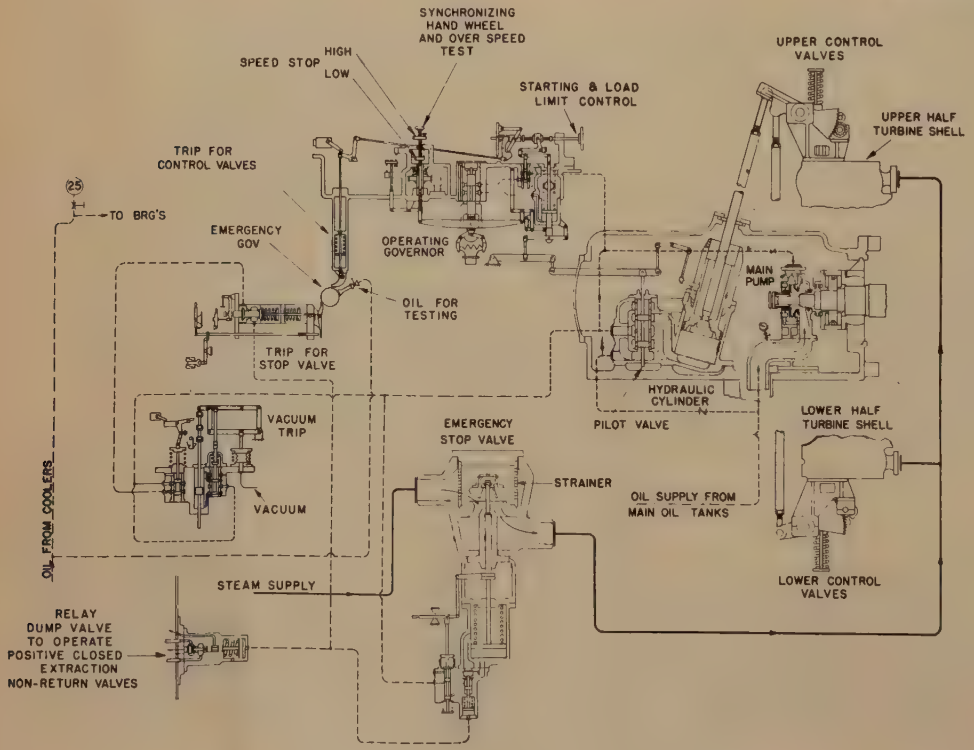


Fig. 20. Schematic diagram of turbine-governing and valve mechanisms

of hardened stems and bushings, such as shown in FIG. 11, rather than soft packings.

A centrifugal main oil pump driven by the turbine shaft is widely used. The arrangement used by the author's Company is illustrated in FIG. 22. In this system[12] a portion of the oil required for lubrication of the bearings passes through a small turbine which in turn drives a booster pump to maintain a positive pressure at main-pump suction. This system has very high efficiency and reduces the size of piping required between the turbine and oil tank usually located at a lower elevation.

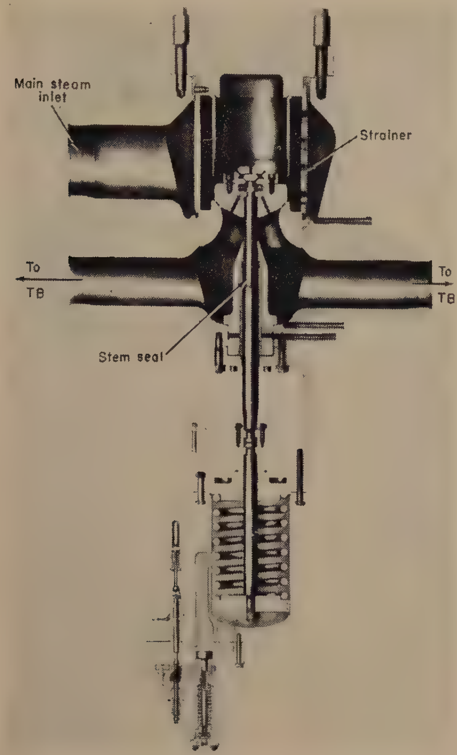


Fig. 21. Cross-section of emergency-stop valve with stem seal to prevent steam leakage along stem

The response rate of governing systems has been increased to provide adequate margins on modern high-speed low-inertia units to prevent tripping of the emergency governor following the instantaneous loss of maximum load. The characteristics of the governing systems meet the specifications of the Joint AIEE-ASME Committee on Prime Mover Speed Governing.[13][14]

As a precaution against oil fires, all piping carrying turbine oil at pressure is guarded by an outer pipe so arranged that should leakage of the pressure line occur it would drain back to the turbine oil tank. In addition, all oil-operated cylinders and other turbine-control parts operated by oil are enclosed in either the oil tank or the turbine standards so that any leakage or breakage of these parts will not allow oil to escape from the oil system and possibly be ignited by hot-steam piping or turbine parts. This not only provides fire protection but also protects against pumping all the oil from the tank, thus losing oil supply to the bearings.

SUMMARY

Rapid growth in the use of electrical energy in the United States and increasing fuel costs created a need for rapid expansion of steam-electric generating capacity with high thermal efficiency. This led to the development of larger 3600-rpm turbines for operation at initial temperatures as high as 1050 F and turbines for the resuperheat cycle utilizing steam conditions as high as 2000 psig, 1050 F initial, and reheat to 1000 F.

Analysis of turbine shipments of the author's Company for central-station service shows the initial temperature and pressure trends for the period of 1947 to 1950 inclusive.

Improvements in construction and materials of turbine parts have been made to meet adequately the requirements of higher temperatures and pressures.

The establishment of a standard in the United States for turbines and generators from 11,500 to 60,000 kw by the users and manufacturers has assisted in meeting the large demand for steam turbine-generators without inhibiting the continued development of improved designs for better steam conditions in the larger sizes.

REFERENCES:

(1)"The 2000 psi, 1050 F and 1000 F Reheat Cycle at the Philip Sporn and Twin Branch Steam-Electric Stations," by Philip Sporn, *Trans. ASME*, vol. 70, 1948, pp. 287-294.

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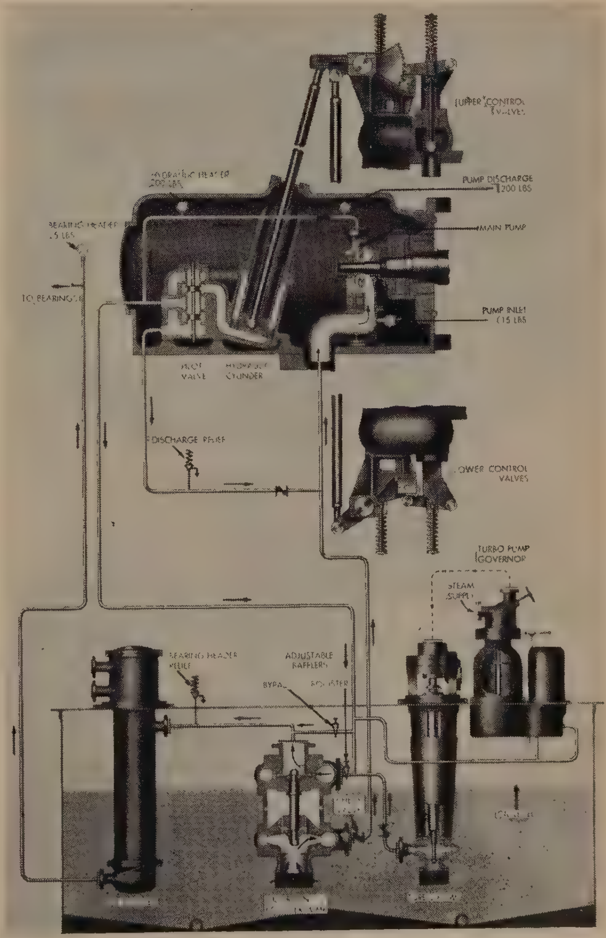

Fig. 22. Schematic diagram of oiling system with shaft-driven centrifugal main oil pump

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PROGRESS IN STEAM-TURBINE DESIGN

(Continued from preceding page)

(2)"Preferred Standards for Large 3600-rpm Three-phase 60-cycle Condensing Steam Turbine-Generators," AIEE publications Nos. 601 and 602, May 1945.

(3)"Heat Rate Test Results of 100,000-kw Essex Turbine-Generator," by V. S. Renton and Stanford Neal, presented June 1949 at Semiannual Meeting, San Francisco, Calif., American Society of Mechanical Engineers, Paper No. 49-SA-19.

(4)"Operating Characteristics of 100,000-kw Essex Turbine-Generator," by V. S. Renton and Stanford Neal, presented June 1949 at Semiannual Meeting, San Francisco, Calif., American Society of Mechanical Engineers, Paper No. 49-SA-28.

(5)"Suitability of Modern Turbine Units," by E. E. Parker and C. W. Elston, *Electric Light and Power*, April 1949, pp. 101 and 102.

(6)"The Design of Sewaren Generating Station and No. 1 Unit at Essex Station, Public Service Electric and Gas Company," by F. P. Fairchild, presented June 1949 at Semiannual Meeting, San Francisco, Calif., American Society of Mechanical Engineers, Paper No. 49-SA-15.

(7)Symposium on Reheat Cycle, *Trans. ASME*, vol. 71, no. 6, 1949, pp. 673-749.

(8)"Developments in Resuperheating in Steam Power Plants," by E. E. Harris and A. O. White, *Trans. ASME*, vol. 71, 1949, pp. 685-691.

(9)"Steam Turbines for Resuperheat Cycle," by E. E. Parker, *Trans. ASME*, vol. 71, no. 6, August 1949, pp. 697-698.

(10)"Progress in Design and Performance of Modern Large Steam Turbines for Generator Drive," by G. B. Warren, *Trans. ASME*, vol. 63, 1941, pp. 49-75.

(11)"Stabilization of Steam Turbine Shafts," by S. H. Weaver, GENERAL ELECTRIC REVIEW, Oct., 1941.

(12)"Turbine-shaft Centrifugal Oil Pump Works With Oil-driven Booster Pump," by R. Sheppard and J. W. Barnett, *Power*, Feb. 1947.

(13)"Prime Mover Speed Governing," AIEE Publication No. 600, July 1944.

(14)"Speed Governing Design Considerations for Multivalve Condensing Steam Turbine-generators," by J. W. Barnett, *AIEE Proc.*, vol. 67, 1948.

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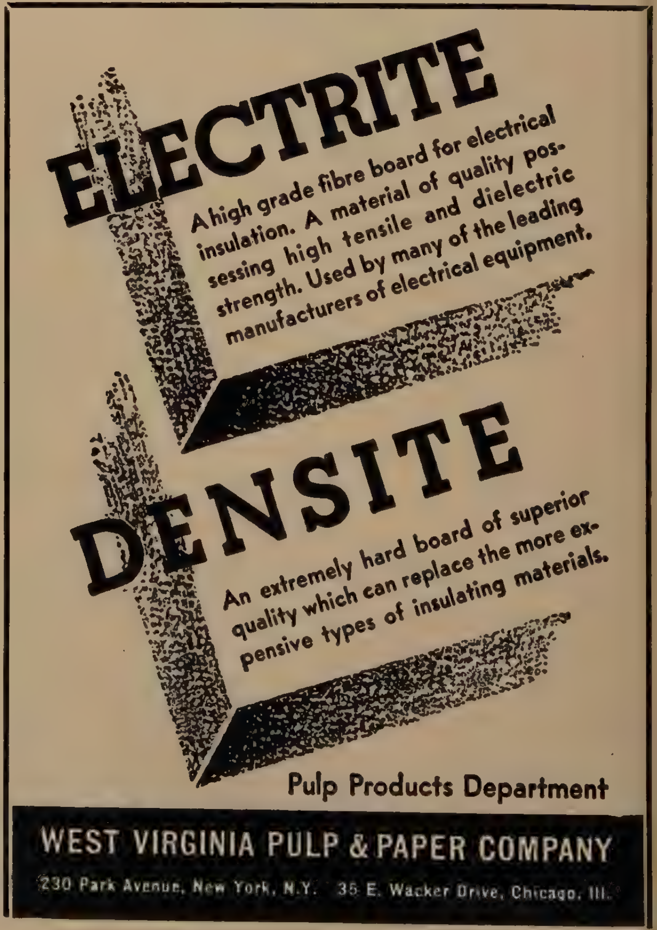

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THE AMPLISTAT AND ITS APPLICATION . . . Part II

The new static power control as used for amplification in small-signal circuits, including a-c as well as d-c signals. Typical forms and applications, with their characteristics

By H. M. OGLE
General Engineering and Consulting Laboratory
General Electric Company

SMALL-SIGNAL AMPLIFICATION

The most important characteristic of an amplifier of small signals is the order of magnitude of the smallest signal which can be amplified. In vacuum-tube circuits t is common to refer to this as the minimum signal which is detectable above the circuit noise. Circuit noise exists in amplistats, but because of the low frequencies involved it is sometimes rather difficult to measure. It is therefore more common to refer to the drift-output signal due to different effects: line-voltage variation, frequency variations, aging of circuit components, temperature, voltage wave shape, etc. It is generally convenient to consider these effects separately and to determine which is the largest in the specific case in question. The minimum detectable signal can then be determined by considering the effect of the larger variables.

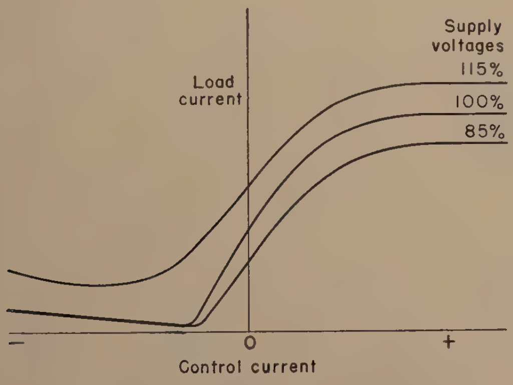


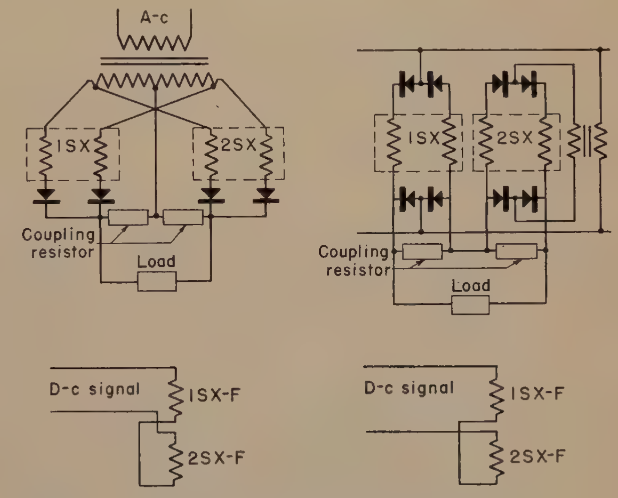
Fig. 7. Amplistat characteristic

The most commonly encountered limitation is that imposed by line-voltage variations. As can be seen in FIG. 7, a small change in line voltage will cause a relatively large change in the output of most simple amplistat circuits. For most applications, some form of compensation for line-voltage change must be made. It is usually not sufficient to balance the output against a signal which is a linear function of line voltage. Some form of nonlinear circuit element is commonly required to give even a fair degree of compensation. The best nonlinear circuit element is an amplistat having the same characteristics as the one being compensated.

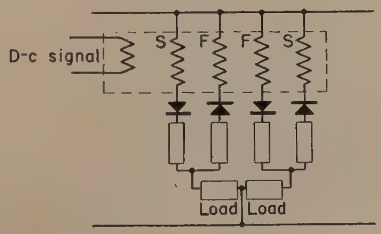
Push-pull Circuits

The second amplistat can just as well be used to assist in getting amplification from the circuit. This is the basis of the push-pull circuit designs which are most commonly used for small-signal amplification. FIG. 8 shows several push-pull circuits, all having in common a low over-all efficiency. The coupling resistors shown in the first two circuits (FIGS. 8a and 8b) will dissipate several times more power than is usually realized in the load. All of the circuits have, however, considerable freedom from the effects of supply voltage and/or frequency variations. In addition these circuits tend to correct for circuit drift due to ambient temperature or component aging, but only to the extent that the components of the circuits are matched in their temperature or aging characteristics.

The center-tap circuit shown in FIG. 8a will have a characteristic, as shown in FIG. 9, that is merely a composite of two characteristics of the type shown in



(a) Push-pull Center Tap (b) Push-pull Bridge



(c) Square

Fig. 8. The amplistat in typical push-pull circuits

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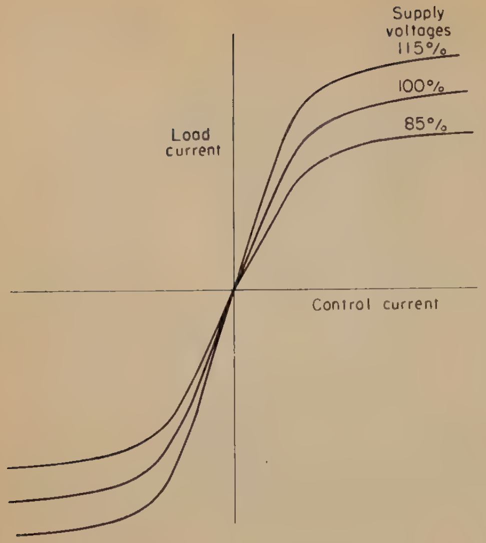

Fig. 9
Amplistat characteristic for push-pull circuits

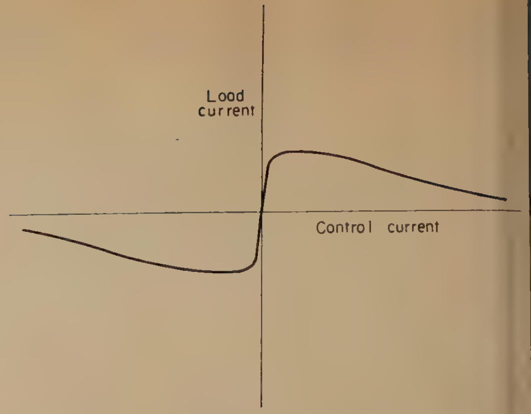

Fig. 10. The extended push-pull characteristic, for large signals

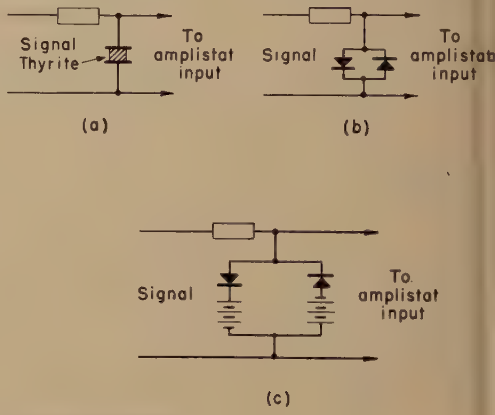

Fig. 11. Limit circuits for signals

FIG. 7. For most signal levels this type of characteristic is entirely adequate. If very large signals are to be encountered during operation of the circuit, however, the extended characteristic (FIG. 10) must be considered.

If an extremely large signal is impressed upon the input of a push-pull amplistat circuit, the output will decrease and asymptotically approach zero. When this characteristic is objectionable, nonlinear circuit elements are sometimes used (FIG. 11) to prevent very large signals from being applied to the input. At times, this problem is solved by the use of multistage amplifiers whose input stage is used over only a small portion of the characteristic.

The coupling resistors, which are shown in the center-tap and bridge circuits of FIG. 8, are usually selected to be one and one-half times the resistance of the load. This value is sometimes modified so that the rating of the rectifiers or the a-c windings of the reactor will not be exceeded, or that an output signal having a given voltage level can be obtained.

Bias windings are, in some cases, put on the reactors that are to be used in push-pull circuits so that each reactor will be operating at or near its maximum gain; the exact setting of the currents in these windings can be modified to give optimum supply-voltage stability. The reactors used in push-pull circuits are normally operated at a voltage somewhat higher than that which is considered optimum, giving a greater power output from each individual reactor but not permitting the reactor to reduce its output current to a very low value. This, of course, is not important in the push-pull circuits because the load current can always go to zero, but better stability with varying supply voltage is normally achieved in this manner.

Plug-in Forms

In FIG. 12 a complete push-pull amplistat stage is shown assembled in a plug-in form. The unit is connected as shown in the diagram of FIG. 13, and is similar to the circuit in FIG. 8a except that negative feedback windings have been incorporated. These feedback windings greatly increase the stability of the over-all unit and provide an extremely linear characteristic. As can be seen in FIG. 14, supply voltage has very little effect upon this unit.

The square circuit in FIG. 8c can be used with coupling resistors but is normally used with a center-tapped load. This load may be a center-tapped winding of a relay, machine field, or the input winding of another amplistat. As shown in FIG. 8c, series resistors are necessary in each arm of the square circuit in order to minimize circulating currents. In many applications of this circuit the resistance may be simply that of the a-c windings combined with the forward resistance of the rectifiers. Because such resistance is normally present in a significant amount in all amplistats of small size, the square circuit is usually considered more efficient than either of the other push-pull circuit arrangements. A plug-in version of the square-circuit amplistat is shown in FIG. 15.

Fig. 12
Push-pull amplistat stage assembled in plug-in form

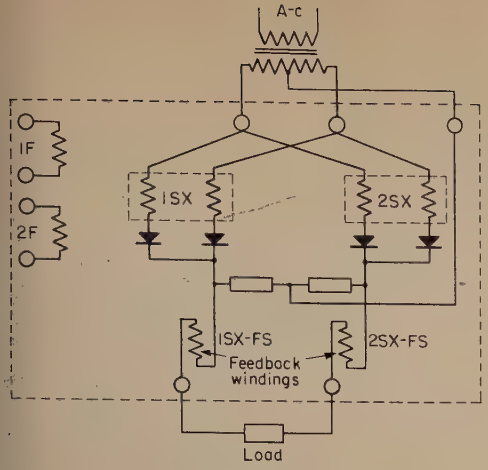

Fig. 13. Circuit for the plug-in unit shown in Fig. 12

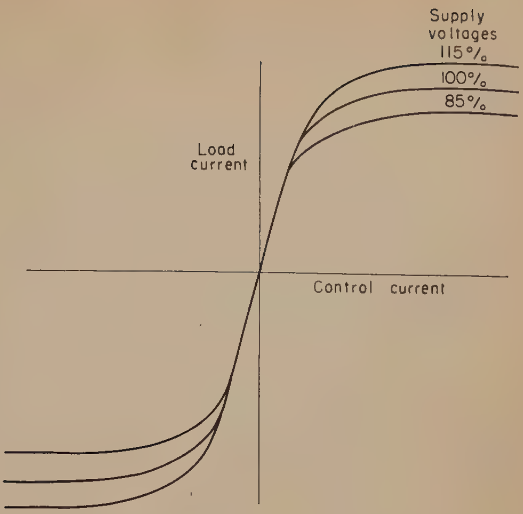

Fig. 14 Characteristic of the plug-in unit

Thermocouples

One of the most common applications for a small-signal amplifier is the job of amplifying the output of a thermocouple or thermopile. As this output is d-c and usually of low impedance, the job can be very easily done with amplistats. With the use of a few turns of large wire as the signal winding of the amplistat, a very low input impedance can be obtained and a good match made with the thermocouple. For most such applications an input resistance between one and ten ohms is used. This does not result in an optimum impedance match, but minimizes the effect of variations in lead resistance caused by ambient-temperature changes.

When thermocouples are used in a temperature-limit circuit it is often desirable to have no output from the amplifier until the temperature of the thermocouple exceeds a given value. Since blocking rectifiers do not usually work well in a thermocouple circuit because of the small voltages involved, the thermocouple output is usually amplified by one or two push-pull stages before a blocking rectifier is used. Even when only a single-sided output from these stages is used, it is advisable that they be push-pull in order to minimize drift and line-voltage effects.

Another interesting application of the amplistat is that of a flame-detector amplifier. A small thermopile consisting of several bare thermojunctions is inserted in the fire box or combustion chamber in which flame is to be detected. The hot junctions are so arranged that they directly view the flame; the cold junctions are near by and in the same atmosphere as the hot junctions but are shielded from receiving direct radiation from the flame. (In most applications it is not advisable to use a vacuum thermopile or similar device having a window through which the radiation must pass, as such a window is easily covered with soot and the thermopile rendered useless. When bare-wire thermojunctions are used, even a relatively thick layer of soot will have little effect upon the output.) Under a low fire condition such a device will have an output of several millivolts, which must be amplified to a value sufficient to operate a sturdy relay. In the flame-detector amplifier shown in Fig. 16, two plug-in push-pull stages are used to amplify the output of the thermopile. The output from the second plug-in stage is applied directly to the relay coil.

Resistance Bulb

A common method of measuring temperature involves the use of a resistance bulb, consisting of a coil of resistance wire of known temperature coefficient, placed in a metal bulb for mechanical protection. The bulb is so connected as to form one arm of a bridge circuit, and the bridge will be in balance only when the

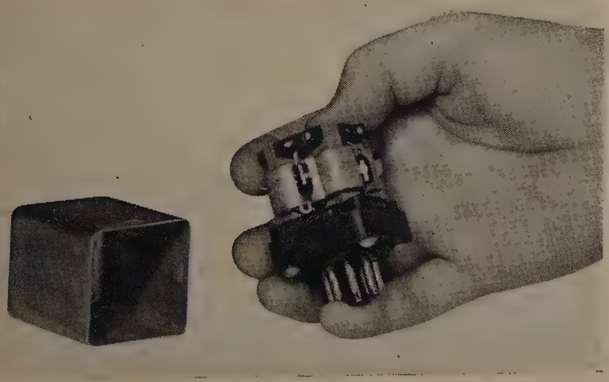

Fig. 15. The square-circuit amplistat in plug-in form

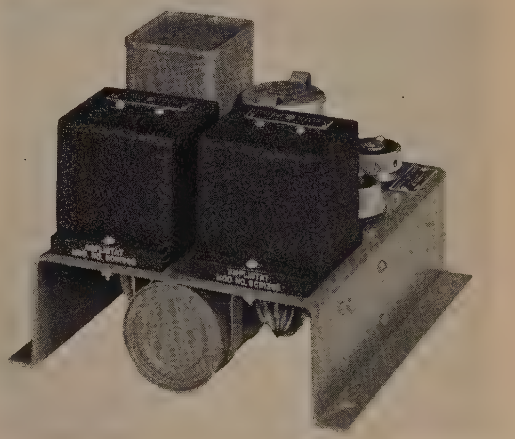

Fig. 16 Amplistat used in a flame detector amplifier

bulb is at one specific temperature. This method of temperature measurement is convenient in that no reference voltage is required, as is the case with a thermocouple, and it is capable of giving a much larger output than the thermocouple. Its one major disadvantage is in the fact that in order to take power out of the bridge circuit it is necessary to dissipate a considerable amount of power in the resistance bulb itself.

If the medium whose temperature is being measured does not have a high heat content, the power dissipated in the bulb will increase its temperature a significant amount and destroy the accuracy of the measurement. By the use of an amplistat to amplify the output of the bridge circuit, the power dissipated in the bulb can be kept to the minimum. In most cases such an amplifier would be very similar to a thermocouple amplifier and should, in general, be of push-pull design.

Photocells

Photoelectric cells give an output which can easily be amplified with the amplistat. The main problem in such applications is achieving an input impedance sufficiently high to properly match the photoelectric cell. In most practical cases this input impedance is limited by the minimum wire size available and the distribution of the allowable window space of the reactor core. Most amplistats used in photocell circuits have input resistances in the order of several thousand ohms. External resistance is connected in series with this control winding if it is required for protection of the photocell. In general, the internal impedance of the photo cell itself is so great that the time constant of the input circuit is negligible for most control work.

Barrier-layer photocells, also, can be used with amplistats. In this case the internal impedance of the cell (usually about 5000 ohms) can easily be matched to the amplistat input. Good power transfer can thus be obtained, and the total amount of amplification required is usually small. An interesting effect occurs with barrier-layer cells, however, which tends to restrict their use with amplistats. This is caused by the fact that the input circuit of an amplistat usually contains some induced second-harmonic voltage, varying in amount as the amplistat load current varies.

The barrier-layer photocell, besides producing voltage as a result of incident light, tends to function as a rectifier. The induced voltage is rectified by this effect and the amplistat thereby biased to another operating point. By properly connecting the cell to the amplistat it is possible to make use of the bias to produce additional gain from the amplifier. An increase in incident light will cause an increase in the amplistat output, which in turn will cause an increase in the induced harmonic voltages and thereby an increase in bias. The change in bias may cause a further increase in the output of the amplistat which, in some cases, may be so great as to give the circuit a snap action. The amount of bias is not fixed, however, and will vary with the temperature or the aging of the barrier-layer cell. Because the bias is so greatly affected by the cell characteristics, it is usually advisable to put a filter between the barrier-layer cell and the input to the amplistat. This will prevent rectification of the induced harmonic voltages and will produce a much more stable system.

A-c Signals

The amplistat can be used to amplify a-c signals as well as d-c signals. In one case of importance—when the signals are of the same frequency as the power supply—it is usually necessary to discriminate between the phase of the signal and that of the power supply. The signal is converted into d-c of corresponding polarity and can subsequently be amplified by a conventional amplistat. A device used for this purpose is called an amplistat discriminator.

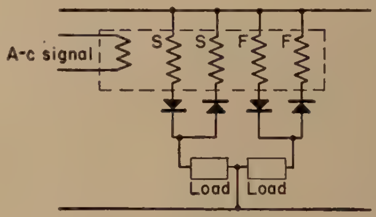

Fig. 17. Circuit for the amplistat discriminator

One possible circuit for such a discriminator, shown in Fig. 17, is very similar in operation to that of the conventional amplistat circuit. The only difference in the connection is the polarity of two of the a-c windings. By reversing these windings the output of the amplistat can be made to respond to the phase of the a-c input signal. In most applications (such as the signal obtained from a selsyn or a magnetic bridge) the signal is either in phase with the power supply or 180 degrees out of phase. The output of the discriminator circuit, working from such a signal, will have a polarity that depends upon this phase and an amplitude that is a function of the signal amplitude.

It is usually desirable to have the input impedance of the discriminator as high as possible; in that way very little current will be drawn from the selsyn or magnetic bridge, and its accuracy will therefore be enhanced. The discriminator circuit automatically provides this high impedance.

By the reversal of one a-c winding of a conventional amplistat, a large induced voltage of fundamental frequency will be realized in the control circuit for each pair of saturable cores. When there is no input signal, the induced voltage from one pair of cores exactly cancels the induced voltage from the other. When a small signal is applied, however, this balance condition is upset and a resultant induced voltage appears in the signal circuit. This voltage is of such a phase as to oppose the signal voltage, and will therefore cause the signal circuit to present a high impedance to the signal source.

(*To be continued*)

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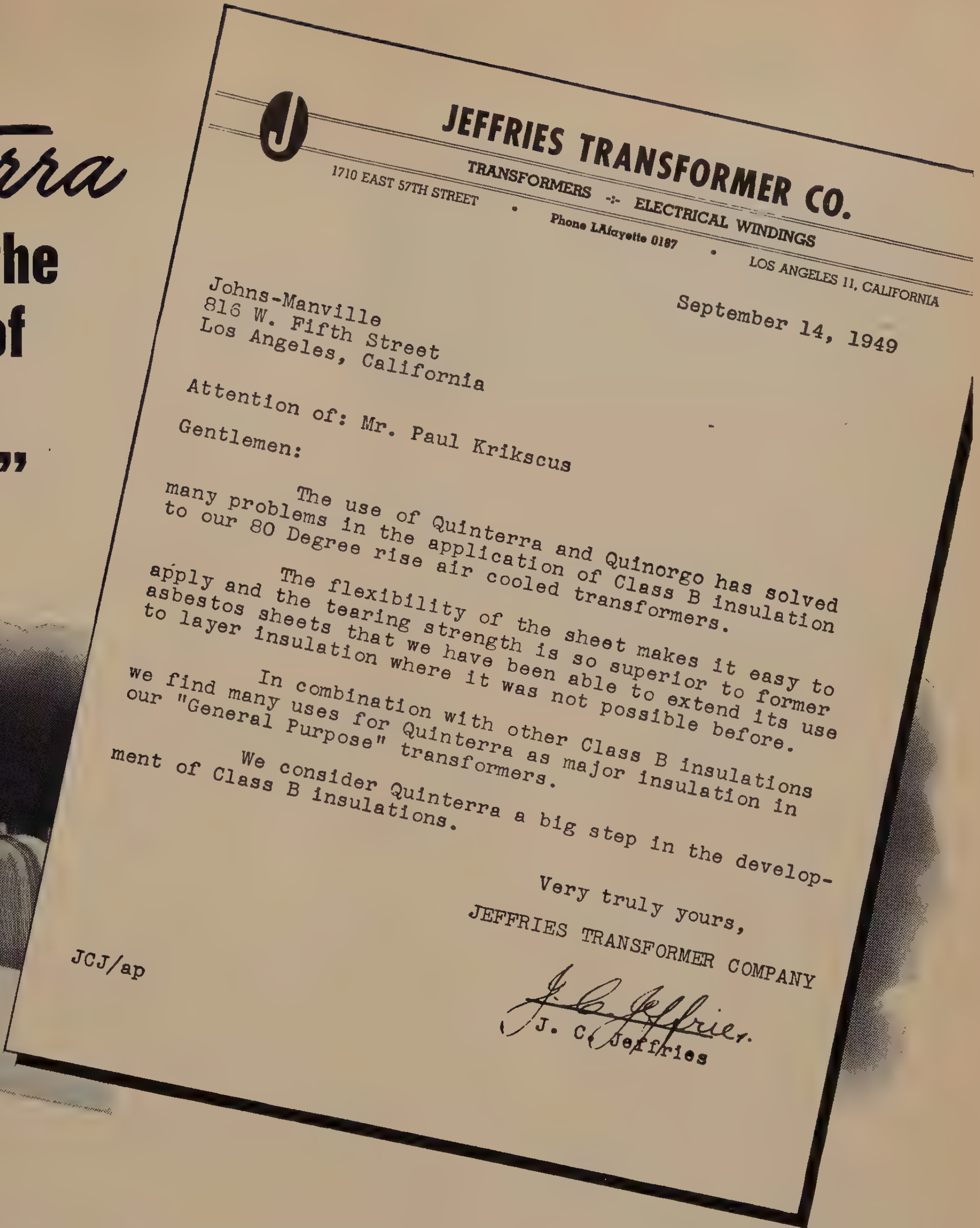

JEFFRIES TRANSFORMER CO.
TRANSFORMERS -:- ELECTRICAL WINDINGS
1710 EAST 57TH STREET • Phone LAfayette 0187 • LOS ANGELES 11, CALIFORNIA

September 14, 1949

Johns-Manville
816 W. Fifth Street
Los Angeles, California

Attention of: Mr. Paul Kriksсus

Gentlemen:

The use of Quinterra and Quinorgo has solved many problems in the application of Class B insulation to our 80 Degree rise air cooled transformers.

The flexibility of the sheet makes it easy to apply and the tearing strength is so superior to former asbestos sheets that we have been able to extend its use to layer insulation where it was not possible before.

In combination with other Class B insulations we find many uses for Quinterra as major insulation in our "General Purpose" transformers.

We consider Quinterra a big step in the development of Class B insulations.

Very truly yours,
JEFFRIES TRANSFORMER COMPANY

J. C. Jeffries
J. C. Jeffries

JCJ/ap

One after another, transformer companies like Jeffries are "discovering" Quinterra—the revolutionary, new Johns-Manville purified asbestos, high-temperature, electrical insulation.

. . . And, like Jeffries, they're discovering that Quinterra in a transformer gives them important selling advantages . . . as well as providing many savings in transformer design and production.

Quinterra is a paper-thin flexible, continuous sheet insulation. It is being widely used for interlayer and wrapper insulation in transformers and coils.

Its lasting dielectric strength, due to its resistance to pyrolysis, assures a greater safety factor and longer operating life. Quinterra withstands substantially higher temperatures than the hot-spot limit of 130C for Class B insulations.

QUINTERRA

- ✓ cuts factory rejects
- ✓ reduces complaints
- ✓ improves production rate
- ✓ produces more uniform product
- ✓ cuts costs of operations

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ELECTRICAL INSULATIONS

Johns-Manville
Box 290, New York 16, N. Y.

Kindly send me a copy of
Johns-Manville Quinterra Electrical Insulation EL-34A.

Name______________________________

Company________________ Position____________

Address____________________________

City____________________ State__________

G.E.-8

HIGH LIGHTS AND SIDE LIGHTS

"A Chance to Play"

A nationwide campaign is underway to stimulate large-scale outdoor recreation on a community level. As a part of a program designed to help community and industrial leaders in planning better recreation facilities, "A Chance to Play," a 20-minute film documenting the benefit of more play time and improved equipment, was produced for the General Electric Company by the March of Time under the technical supervision of the National Recreation Association.

The movie is part of the material being made available to communities, through G.E.'s More Power to America series, to stimulate public recognition of the need for adequate day and night facilities for all age groups in all seasons and to encourage public-spirited organizations and individuals to campaign actively for planned recreation areas.

Power Under the Great Divide

The difficult feat of installing a 69,000-volt electric power transmission line in the U. S. Bureau of Reclamation's 13½-mile Alva B. Adams Irrigation Tunnel, which goes through the Continental Divide, has recently been completed. The primary purpose of the tunnel is to carry irrigation water from the western slope of the Rocky Mountains in Colorado to the eastern slope. The cable line utilizes the tunnel as an economical route for electric-power transfer between generating plants on the two sides of the Divide.

The complexity of this cable installation resulted from the fact that it was necessary to bring all material and workmen into the 9¾-ft-diameter tunnel from one end only, since no other access points were available. The 69,000-volt cable is a high-pressure gas-filled type which utilizes a $5\frac{9}{16}$-in-diameter steel pipe as a container. The entire steel pipe is welded together to form effectively one continuous pipe, which is hung from the tunnel ceiling where it will be just above the normal water level. In operation, the pipe is filled with nitrogen gas at 200-lb pressure. This gas improves the electrical strength of the oil-impregnated paper insulation of the copper conductors and also prevents air and water from entering the pipe in case of leaks.

The pipe was welded into half-mile sections outside the tunnel and three cables pulled into each section. The pipe was then pulled up a wooden track into the tunnel, raised to the ceiling, and joined to the preceding lengths.

Longer Life for Brushes

Brushes for motors or generators in high-altitude aircraft may have their useful life increased many thousands of times as the result of new lubrication methods recently devised.

Graphite consists of layers of atoms which can slide easily over each other, and it was formerly supposed that this property was inherent in the graphite alone. It has been found, however, that an invisibly thin film of moisture on graphite is required for its lubrication. In tests for wear against a revolving copper disk in a vacuum chamber, dry graphite brushes were worn as fast as an inch within one hour. When a small amount of water vapor was admitted to the chamber, the wear rate was reduced to less than a thousandth as much.

For electric motors and generators working on the ground, the wear of brushes is no great problem, since there is generally enough water vapor in the air to provide the lubricating film of moisture. But modern aircraft, such as jet aircraft, fly at great altitudes in rarefied air at such a low temperature that water vapor is almost completely absent. Many motors and generators are required in such planes. Various methods of treating brushes chemically to prolong their lives have been tried, but still further improvement is needed.

A means has been devised for shielding the parts of electric equipment where the brushes are used, and supplying water vapor to the space around them. In tests with this equipment, brushes which wear out in an hour without water vapor have lasted from 2000 to 8000 hours.

Further developments are now being carried on, to apply the findings to actual aircraft in which the wide range of operating conditions impose some problems that have yet to be solved. The practical merits of equipment with shielded parts are undergoing evaluation in comparison with equipment using chemically treated brushes.

Simple Checking of Low-level Lighting

A new lightmeter has been designed to aid lighting specialists and law-enforcement and safety officials in checking low levels of illumination both indoors and out.

Since much street lighting is below one-half footcandle, it is so dim that it cannot be measured by equipment readily available, such as photographic lightmeters. Previously, the devices most widely used to record very low light intensities were bulky, difficult to transport, and could be operated only by trained technicians. This handicapped extensive survey work by

Half-mile sections of pipe and cable being moved up the winding road toward tunnel through the Great Divide (*Photo courtesy of Electrical Constructors, Inc. and C. M. Elliott*)

Three 69-kv cables being pulled into bell-mouthed feed-in tube on the end of a section of pipe (*Photo courtesy of Electrical Constructors, Inc. and C. M. Elliott*) w-enforcement, safety, lighting, and vic groups attempting to combat crime nd motor vehicle accidents through better ghting of streets and highways.

The new ultrasensitive, portable lighteter will measure accurately illuminaon levels characteristic of street lighting. fits into a carrying case the size of an vernight bag and consists of two units—a etector and an indicator. The detector, a ght-sensitive cell, is self-leveling, mounted n a gimbal. The operator places it at e point where he desires to measure the ght level, and takes the reading from the cale of the small indicator, which may be eld in the hand and which is connected o the detector by a 10-ft lead. The instruent is calibrated to take readings from 0 o 1 footcandle and from 0 to 5 footcandles.

The meter will be valuable to law fficers in taking light readings at accident cenes. The relationship between lighting nd accidents has been cited by President Truman's Highway Safety Committee, vhich recently noted that better street ighting would prevent many of the 18,000 raffic fatalities which occur annually on treets and highways.

Units of the new lightmeter—detector and indicator—and their carrying case

Diesel-electrics for Guatemala

Six 120-ton, 1200-hp diesel-electric locomotives, believed to be the largest, in orsepower, single-cab diesel-electrics for ny gage narrower than standard ever uilt for export, have recently been built or shipment to Guatemala.

The locomotives will be used in tandem —two units at the head of the train and wo "helpers" in the middle. A total of 800 hp will be available on a single train. The use of this amount of horsepower on a 6-in.-gage track is most unusual. Through se of a dynamic-braking system, two of the nits will be able to bring the empty train ack down the grade to the coast.

This equipment is required for heavy auls on the International Railways of Central America, where grades from the owlands to the summit of the Continental Divide range up to 3.6 percent.

An unusual wheel arrangement is used o provide sufficient motored axles to develop the extremely high horsepower demanded on the narrow gage. The C-B-C arrangement consists of two three-axle trucks and one two-axle truck, each truck side-equalized and articulated. The three-axle trucks carry the weight of the superstructure on centerplates and transfer part of the weight to the two-axle truck through load-carrying articulations.

4800 hp—two pairs of diesel-electric units—on a single 36-in.-gage track

Each locomotive is equipped with one power plant, consisting of a 1000-rpm 12-cylinder V-type supercharged diesel engine and a direct-connected separately excited d-c generator. The generator is equipped with a winding which permits it to be used for cranking the engine by storage-battery power. There are eight self-ventilated traction motors on each locomotive.

The locomotive is equipped with single-station, multiple-unit control, with the operator's station placed on the righthand side of the cab. Dynamic braking is supplied.

Total weight for each unit is 240,000 lb. Maximum permissible speed is 40 mph. The locomotive coupled to the train is designed for operation over curves having a radius of not less than 230 ft without binding in the track or interference of parts.

New Water Purifier

An instrument known as a "dew-point recorder" and a new water-purification process that uses no unpalatable chemicals is giving a spring-water taste to water from the Schuylkill River. A new Philadelphia plant, the largest water-purification installation in the United States using ozone to kill river-water bacteria, is using the new method.

In the ozone process, outside air is compressed, cooled, and dried, then is blown past banks of metal plates charged with high voltage. The electricity from the plates causes an electrostatic discharge to take place within the passing air, producing ozone.

As the air passes over the metal plates which cause the electrical discharge, it must have a very low moisture content. To assure that moisture in the air remains constant during the process, the dew-point recorder is used. This instrument gives a continuous record of air dryness by measuring and recording the temperature at which moisture in the air condenses on a mirror's surface.

The ozone is bubbled through river water from which the sediment has been allowed to settle. Being an unstable gas, the ozone breaks down again into ordinary oxygen, and in the process it kills the bacteria in the water.

Finally the water is filtered and pumped into city mains, with only a trace of chlorine added to protect its purity from the time it leaves the reservoir until it reaches the city's water faucets.

1840-mile System of Radio Communications

Equipment for the world's longest microwave radio communications system is being planned and assembled for use in the operation and maintenance of a 1840-mile pipe line now under construction between Mercedes (Tex.) and New York City.

The communications system will cover the entire pipe line through which natural gas will be delivered from fields in Texas and Louisiana to distributors, and eventually homes, in Pennsylvania, New Jersey, and New York.

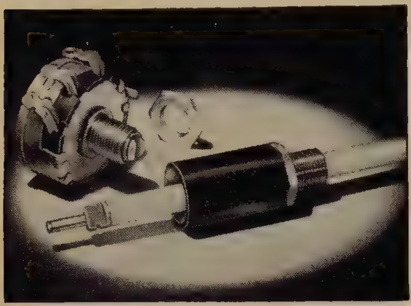
Pipe-line officials in district offices, main terminal, and intermediate compressor stations will be able to talk over the entire route as they exchange operational and sales details by microwave communications. Initial plans call for installation of radio facilities the equivalent of seven telephone lines—two "party lines" spanning the entire 1840 miles, and five private lines from the Houston terminal to district offices. These facilities may be expanded to provide more channels at a later date.

Station attendants along the pipe line will be able to talk with their mobile maintenance crews, equipped with narrow-band two-way radio. The microwave equipment will operate in the 2000-mc band and will employ pulse time division multiplex. Thirty unattended radio repeater stations will be installed as part of the over-all system.

NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

High-voltage Coupler

An attachable high-voltage coupler and spacer assembly, 59-186, with nylon insulator shaft, for use in TV, oscillograph, and other high-voltage circuits. This coupler rounds out an assortment of several Pick-A-Shafts or attachable shaft types and can be purchased separately. The high-voltage insulator sleeve screws on to the control bushing; its threaded metal-stud end takes the mounting nut. The nylon shaft with keyed end slips into the control's slot and is gently tapped to snap it firmly and permanently in place for the integral control and shaft combination. The high-voltage coupler is rated at 10,000 volts breakdown test.—*Clarostat Mfg. Co., Inc., Dover, N. H.*



Timer

A new timer designed to reduce the burden of footwork and the risk of human error in operating screens and pumps in power plants and other municipal and industrial plants. Timing operations are controlled by means of an automatic rotor timer and an integrated system of wire terminals and controls, enclosed in a single cabinet. One person at a single point can thus control the operations of machinery at several points in one or several buildings.

Any number of pumps and screens can be operated for any desired periods of time. Timing rotors are easily interchangeable, and manual operation can be substituted for automatic operation by a quick switch-over.—*Midwest Automatic Control Co., 510 Third St., Des Moines, Iowa.*

Variable-speed Control

A new line of Fra-Sure variable-speed transmissions for fractional horsepower motors. Operating components consist of a double-grooved pulley on a floating-type jackshaft with one groove of the pulley driven by the motor and the other groove driving the machine by section V belts. These belts, with the aid of springs on both sides of the end faces, control flanges to assure alignment. The flanges are of aluminum accurately machined to prolong belt life.

The rate of speed can be changed easily and set by a simple knob movement; constant selected speeds are assured. An automatic speed-locking device keeps the pulley in the desired position throughout the entire 3:1 ratio.—*Frazier & Son, 338 Cortlandt St., Belleville, New Jersey.*

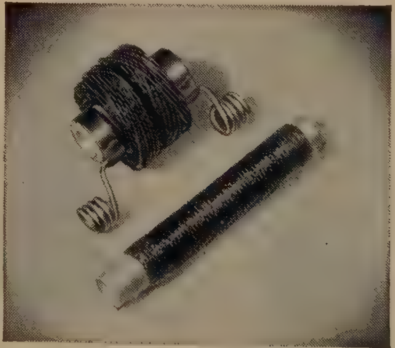
Wax Activator

An efficient spreading agent, called Paraspred, for paraffin and microcrystalline waxes. It is a nontoxic, soft, waxy solid, cream to yellow in color, with a melting range of 92 to 97 F or 33 to 37 C. Use of this product causes greater penetration of the wax into porous materials, such as paper and textiles. As little as one percent added to paraffin wax causes it to spread readily, even on damp surfaces. Ten percent plasticizes paraffin wax to give very flexible, thin coatings of wax. Samples are available on request.—*Glyco Products Co., Inc., 26 Court St., Brooklyn 2, N. Y.*

Radio Interference Locator

A new radio interference locator, Model 302, for the 550-kc to 30-mc frequency range, designed specifically for use by public utility troubleshooters, those interested in man-made radio noise location and reduction, and for power line preventive maintenance work. The instrument utilizes a sensitive 8-tube superheterodyne circuit and operates either from self-contained batteries or 115-volt mains. Each locator is supplied with both a loop and a collapsible rod antenna for normal use. An r-f search probe, insulated for 35,000 volts a-c, is also available for field use as is an audio probe for circulating-current faults and cable-fault location.—*Sprague Products Co., North Adams, Mass.*

Coils and Chokes



A new line of coils and chokes adaptable to tailor-made specifications. Types include high-Q radio-frequency chokes, progressively wound slug-tuned broadcast coils, and oscillator coils, all of which have characteristics not readily matched by standard coil types. These r-f chokes can be made up as two separate coils having a specified coupling coefficient. High-permeability iron cores are sometimes used to provide greater inductance in a small unit.—*Shallcross Manufacturing Co., Collingdale, Pa.*

T Sections

Hot rolled Inconel in equal T sections in standard size of 1½ in. by 1½ in. by ¼ in in lengths up to 15 ft. Weight is approx mately 2¾ lb per foot. The primary purpos of these sections is to provide manufacture of furnaces and other high-temperatur equipment with ready-made and uniform structural parts at considerable econom over the cost of fabricating those parts i their own shops. The sections can be welde riveted, or otherwise joined without difficulty. Similar sections can be produced als in nickel and Monel where tonnage demand are sufficiently high in standard sizes.— *International Nickel Co., Inc., Huntingto West Va.*

Stainless Steel

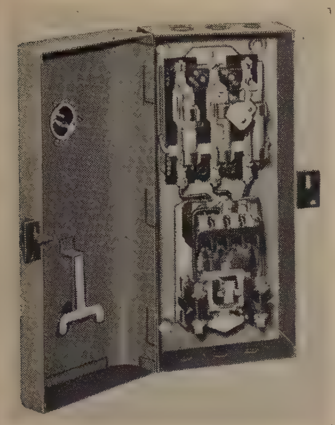
A new stainless steel, 430 ELC, for television picture tubes. The necessary requirements to insure even contraction after glas sealing have been obtained without the us of stabilizing elements by reducing th carbon content to below 0.03 percent Absence of any thermal arrest in coolin from glass-sealing temperature and a rat of contraction compatible with that of glas insures that strains at the seal are wel within satisfactory limits. Fabricating qualities are also satisfactory; it can be spu and formed equally as well as the stabilize 17-percent chromium stainless steel no used. Advantages of the metal-glass iconoscope are: faster, more economical production; lighter weight and greater durability less danger of breakage; and simplifie shipping, because tubes can be shipped assembled in the set.—*Armco Steel Corp. Middletown, Ohio.*

Single-phase Motor

A new repulsion-induction motor, Typ SCR, for use where a constant-speed high torque single-phase motor is required i large ratings. It is available in 5-, 7½-, an 10-hp ratings, all 1800 rpm. The 5-hp uni operates on 115/230 volts; the other tw use 230 volts. The motor, of the open drip proof type, has many features that contribute to long life and aid in installation an maintenance. The Tri-Clad motor construc tion affords triple protection against physical damage, electrical breakdown, an operating wear and tear. Typical applications include air and refrigeration compressors; pumps; stokers; floor surfacers and farm uses such as barn hay curin wood sawing, silo filling, cold storage, fee grinding, etc.—*General Electric Co., Sma and Medium Motor Divisions, Schenectad 5, N. Y.*

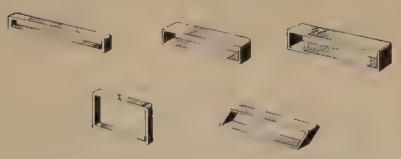
Magnetic Starters

New compact Bulletin 4120 a-c combina-ion magnetic starters with disconnect witches in both fusible and nonfusible ypes for industrial and commercial use where a magnetic full-voltage starter oupled with disconnect means at starter ocation is preferred over separately mounted components. Features of these



tarters include front operation, maximum afety, simplified installation, thermal over-oad protection, high-arc interruption ca-pacity, provision for padlocking in ON and OFF position, and interlock protection in ON position. The components conveniently arranged in NEMA Type 1 general-purpose enclosures are internally prewired and com-pletely accessible.—*Ward Leonard Electric Co., Mount Vernon, N. Y.*

Shading Coils



Shading coils or shaders for shaded-pole motors produced from seamless copper or commercial bronze tubing assures uniformity. Use of these seamless shading coils instead of soldered or welded flat wire or ribbon results in improved quality control. Their use also offers an opportunity to improve performance tolerances by eliminating at least one of the variables encountered in a production run. Likewise, a dollars-and-cents saving results because it is not necessary to include the cost of forming, welding, or soldering. With seamless shading coils, it is possible to start larger-size motors by the shaded-pole method than was considered possible previously, thus eliminating split-phase winding or the use of compensators.—*Ilsco Copper Tube and Products, Inc., Cincinnati 27, Ohio.*

Insulating Varnish

A new insulating varnish No. 1100 combines the desirable characteristics of many special formulations into a single general-purpose compound. This clear varnish permeates deep coil layers and quickly bakes hard, to form a solidly bonded winding. It is formulated for stability in storage and dip tank. Its solvent is naphtha, which does not attack magnet wire. Specific

(Continued on next right-hand page)

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GENERAL ELECTRIC

461-10

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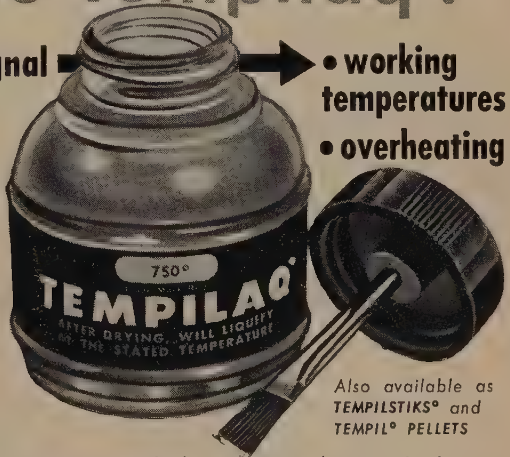

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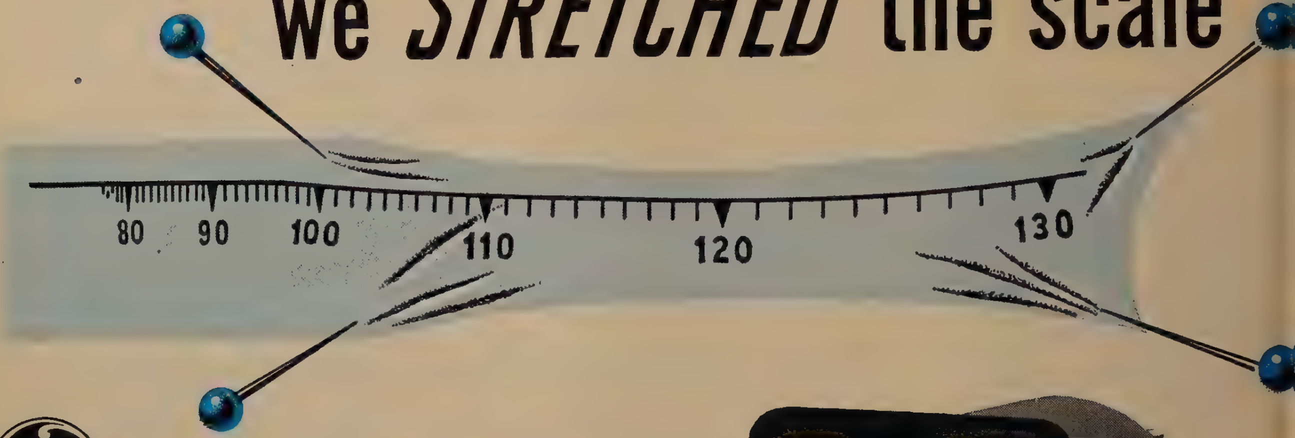
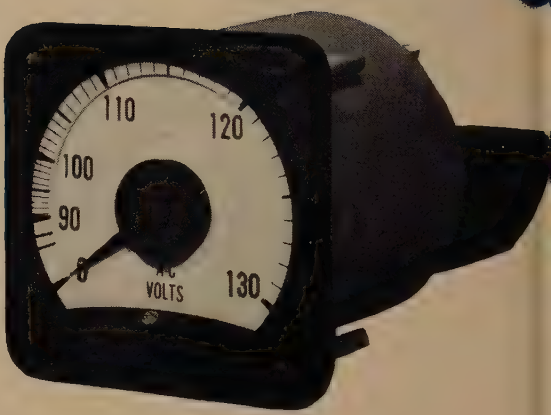


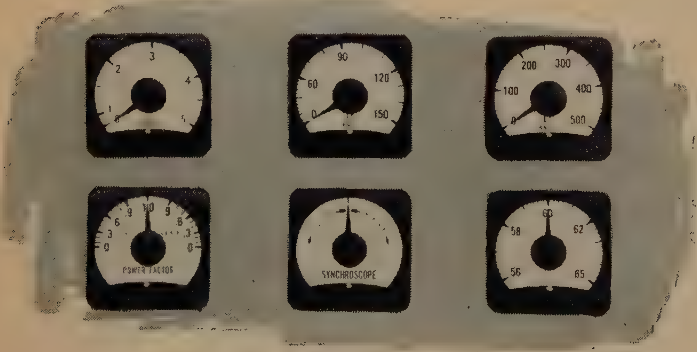
EXPANDED-SCALE VOLTMETER



Now you can read important circuit voltages more accurately! Most common voltages measured in generating stations, substations, or industrial test installations range from 105 to 125 volts. On the G-E expanded-scale voltmeter, the scale has been expanded—stretched out—over this 105- to 125-volt range.

Thus accuracy within ½ of 1 per cent is obtained in the most used range. Over the remainder of the scale, accuracy is within 1 per cent. Because of high operating torque, response time is very fast, too—less than one second for full-scale deflection.

For modern switchboards, specify modern G-E switchboard instruments. Apparatus Dept., General Electric Company, Schenectady 5, N. Y.



The expanded-scale voltmeter is but one of G.E.'s line of long-scale instruments. These instruments are compact—five can be mounted on a 25-inch panel. Yet the long scale gives them a high score on readability. An instrument only 4¼ inches square has a scale 7.1 inches long.

Type CD recorders give permanent records of circuit conditions. Designed for switchboard installation, CD recorders can be mounted close together for space economy and appearance. Available in ink or inkless types.

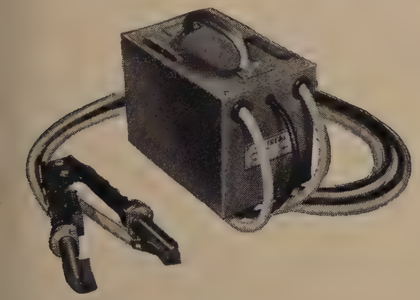
GENERAL ELECTRIC

602-177

gravity for use is optional. Because the varnish is internal-curing, it hardens throughout to a durable oil-proof mass.—*Irvington Varnish & Insulator Co., 6 Argyle Terrace, Irvington 11, New Jersey.*

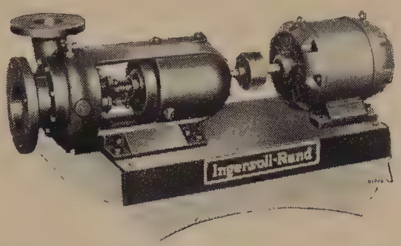
Soldering Tool

A new standard 1000-watt economy model Thermo-Grip soldering tool that operates on the resistance-heating principle. Touching the work with the tool completes the secondary power circuit, and heating begins instantly. Preheating is unnecessary; thus the tool is always ready but draws current only when actually in use and in contact with the work. It also concentrates heat at the point of contact, heating only the part to be soldered. Attachments available include: a plier type for sweating and unsweating copper tubing, soldering lugs, terminals, etc.; a fork type with two 3-in. electrodes for reaching into restricted places; and a pencil type with one 3-in. electrode for spot soldering and light seam soldering.—*Ideal Industries, Inc., Park Ave., Sycamore, Illinois.*



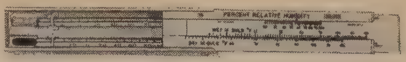
Centrifugal Pumps

A new line of cradle-mounted centrifugal pumps designed with deep water-cooled stuffing box, smothering gland, ring oil-lubricated ball bearings, a heavy cradle shaft and bearing, sturdy channel-steel baseplate, and an all-metal coupling. The impeller is of the latest hydraulic design, mechanically and hydraulically balanced. The pumps are built in five sizes—single- and two-stage—ranging from ¾ to 5 in. discharge with capacities up to 1600 gpm, and heads up to 250 ft. Normal horsepower range is from ¼ to 75 hp. Because of the wide variety of possible drives, the pumps are suitable for paper mills, breweries and distilleries, chemical plants, refineries, building and contracting and general manufacturing processes.—*Ingersoll-Rand Co., 11 Broadway, New York 4, N. Y.*



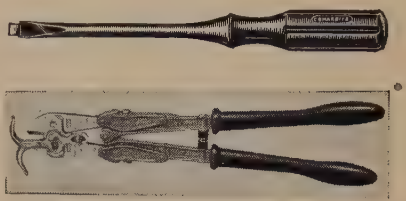
Humidicator

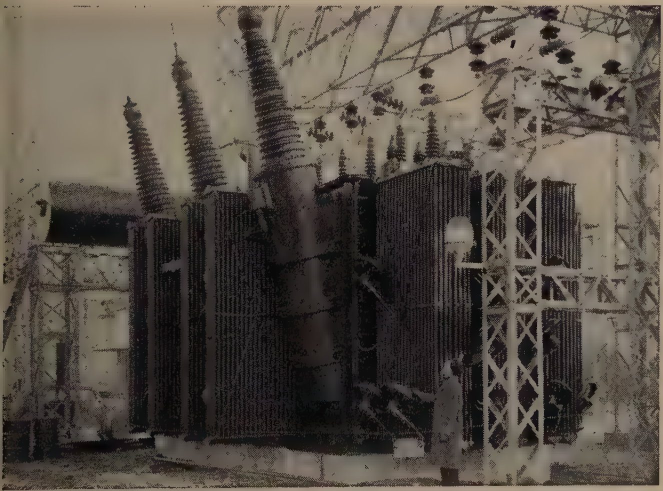
A precision pocket instrument, shorter than a pencil and known as the TAG humidicator, Model 8704, shows relative humidity by the wet-and-dry bulb method. The device can be used either in the hand or mounted on a wall. Securely fastened in a plastic case by integral resilient mountings are two etched-scale glass thermometers, individually hand-calibrated. A psychrometric slide rule forms the cover of the case. For use, a few drops of water are applied to the thermometer wick, and the instrument is fanned or swung for several moments. Setting the wet-bulb reading opposite the dry-bulb reading on the slide rule then indicates relative humidity.—*Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.*



Insulated Tools

New Cohardite insulated tools—meterman's screwdrivers, standard screwdrivers, socket wrenches, wire cutters, and fireman's cutters—designed especially for live work involving dangerous voltages. Use of these tools with rubber gloves for such work provides an extra margin of safety and protection for personnel and equipment. Cohardite was developed specifically to give enduring and safe service in the insulation of hand tools. It maintains its high-dielectric strength over the extreme range of working temperatures and in the presence of moisture, oil, or acid fumes.—*H. K. Porter, Inc., Somerville, Mass.*





One of two 66,000, 215,000 grd Y—60,000 grd Y—12,000 volt, 60 cycle power transformers built by Canadian General Electric for the Horne Payne substation of B. C. Electric Railway Company.

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TRADE LITERATURE

Air Conditioners—A catalog covering a complete line of packaged air conditioners in units of 2-, 3-, 5-, 7½-, and 10-hp capacities for use in offices, homes, stores, restaurants, shops, apartments, hotels, etc. The illustrations include a cutaway drawing showing how the unit operates. Complete data are given for each unit and typical floor-plan sketches are shown. Twelve pages. Catalog No. PM 79-0100.—*General Electric Co., Air Conditioning Department, Bloomfield, New Jersey.*

Copy Reproduction—An attractively designed booklet introducing the Flexoprint method of listing copy for reproduction. All phases of its use are explained with a detailed text and numerous illustrations showing the first step through to the final publication appearance. Twenty-four pages. KD-499.—*Remington Rand, Inc., 315 Fourth Ave., New York 10, N. Y.*

Electronic Terms—The need for an accurate up-to-date reference source of words used in the rapidly expanding electronics field of television, radio, and industrial electronics is supplied by this 6 in. by 9 in. handy-size dictionary of electronic terms. Included are more than 2500 definitions covering mostly modern techniques and equipment, together with over 125 illustrations and diagrams of components, equipment, and electronic circuits. An appendix section also contains useful radio data. Price 25¢. Sixty-four pages.—*Allied Radio Corp., 833 West Jackson Blvd., Chicago 7, Illinois.*

Insulation—The composition of silicone Class H electrical insulation, its effect on motor life, and its use in numerous applications is briefly mentioned. Four pages. *Insulation Manufacturers Corp., 565 W. Washington Blvd., Chicago 6, Ill.*

Lapping—The how and the why of the Lapmaster method of flat lapping to extremely close tolerances on an automatic, high-production basis is interestingly presented by descriptive text and photographic illustrations. A section is devoted to accessories including optical flats, lapping compounds, monochromatic lights, polishing plates, and hand-lapping plates. Twelve pages. Titled "The Lapmaster."—*Crane Packing Co., Dept. D-9, 1800 Cuyler Ave., Chicago 13, Ill.*

Mercury Clutches—A complete line of mercury automatic clutches is described and illustrated in three new bulletins: A description of the clutch in general, listing various applications ranging from air conditioning to washing machines (eight pages) Bulletin 216; Series G clutches as applied to gasoline engines (four pages) Bulletin 217; and Series E clutches for electric motor applications (four pages) Bulletin 218.—*Automatic Steel Products, Inc., Canton, Ohio.*

Rivets—A catalog describing tubular and split rivets in steel, brass, copper, aluminum, nickel-silver, stainless steel, and Monel, listing not only the various types of rivets but the machines used in the various types of assemblies. Twelve pages. Price List No. 39.—*Chicago Rivet & Machine Co., Bellwood, Chicago, Ill.*

Photography—Applications of photography in business and industry are summarized in a new booklet titled "Functiona Photography." Numerous illustrations depict their use of various processes and techniques for research, production, quality control, training, advertising, and sales. Sixteen pages. F1-14.—*Industrial Photographic Division, Eastman Kodak Co., 343 State St., Rochester 4, N. Y.*

Tools—A tooling manual containing many suggestive uses of the various tools described—midget milling, deburring, cutting, counter-sinking, reaming, and miscellaneous—in addition to pertinent technical information. Specifications and prices are given, and numerous illustrations are shown. Thirty-two pages. Catalog No. 18.—*Severance Tool Industry, Inc., Saginaw, Mich.*

Watthour-meter Retirement Evaluator—A brochure titled "Time to Retire Old Watthour Meters?" fully describes a new evaluator based on an economic formula and developed to aid in determining the economic point at which to retire older watthour meters. The evaluator, resembling a circular slide rule, has scales for settings to include such factors as cost of new meters, age of old meters, and excess annual cost of old meters over new meters. Requests for copies of the brochure, which includes the evaluator, should be made on business letterheads. Sixteen pages. GEA-5448.—*General Electric Co., Apparatus Department, Schenectady 5, N. Y.*

BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery; none sent on approval.)

Heat Transfer, Vol. I

Max Jakob—John Wiley & Sons, Inc., New York. 1949. xxix+758 pp. $12.00.

The primary purpose of this volume, together with the second volume, is to provide a systematic and historical presentation of the many concepts and quantitative theories of the entire field of heat transfer. It aims, furthermore, to make it unnecessary for the student to refer to the extensive prewar foreign literature, particularly the German, which contributed so much in this field. Much attention is given also to methods of analysis, to derivations, and to experimental techniques, but the voluminous experimental data on convection available in the literature are reviewed to a relatively limited extent.

The elementary basic principles of conduction, convection, and radiation are first presented followed by a description, from the theoretical viewpoint, of the properties of matter most significant for heat transfer—viscosity, thermal conductivity, and emissivity. The remainder of the book is devoted to detailed consideration of conduction (both transient and steady-state), free and forced convection, evaporation, and condensation.

The present volume is the most comprehensive available on the theoretical aspects of the subjects considered, and should be of great value to students, particularly the more advanced ones, in this field. Some parts do not seem so suitable, however, for the engineer who needs to select quickly the correlation most suitable for some particular problem he encounters in practice. As just one example, in different sections of the book relations between the same basic variables are represented by equations which, although similar in nature, differ quantitatively from each other, and their relative merits are neither adequately covered nor illustrated by plots of test evidence. One of these equations (number 26-37) is valid only for gases, but this limitation is not stated, nor is the choice of temperature for evaluation of the gas properties even discussed.

R. Hosmer Norris

Fluorescence and Phosphorescence

Peter Pringsheim—Interscience Publishers, Inc., New York. 1949. xvi+794 pp. $15.00.

In this 800-page treatise Peter Pringsheim, for thirty years an outstanding scientist in the field of luminescence, has presented comprehensively the published scientific aspects of photoluminescence. Both the fluorescence of monatomic, diatomic, and polyatomic gases and vapors and the fluorescence and phosphorescence of condensed systems are treated with equal understanding and thoroughness. Technical applications are ignored. Cathodoluminescence is not included.

The text is almost entirely descriptive and is adequately supplemented by plots and photographs. As in any treatise of this size and scope, there are errors, but they are largely confined to minor typographical and transcription errors. The only significant limitation of the book is that many of the data and interpretations are presented without apparent critical evaluation.

In addition to a subject index, an exhaustive bibliography of books and articles from 1908 through 1947 is included, with a novel reference index to locate readily the page numbers describing the work of a particular scientist.

Dr. Pringsheim has brilliantly climaxed a long and productive career in photoluminescence with the publication of this treatise.

Ferd E. Williams

Industrial Chemistry (5th Edition)

E. Raymond Riegel—Reinhold Publishing Corp., New York. 1949. xiii+1015 pp. $7.00.

The fifth edition of this well-known text book is of the same high quality as previous editions. All old chapters have been revised and brought up to date, and several new chapters are added that describe chemical operations and materials developed since the previous revision. These include such materials as antibiotics, insecticides, fungicides, and plastics and such operations as the utilization of wood and the application of dyestuffs and of atomic energy.

The illustrations and diagrams always aid in the understanding of a described process or operation. Some typographical errors have slipped through, however, and while not serious may cause some confusion.

Production tables included are helpful in judging the size of stable industries but are quickly outdated in fast-growing ones and must be used with that reservation. References for further reading and patent references are stimulating to the student but could be brought more up-to-date in certain chapters.

The book is excellent as an elementary text for students of industrial chemistry and will also serve as a reference for the busy executive who simply wishes a brief review of the general chemical industry.

E. F. Fiedler

Frequency Modulated Radar

David G. C. Luck—McGraw-Hill Book Co., Inc., New York. 1949. xviii+466 pp. $4.00.

With the exception of research work done at Columbia University, this book, originally written as a comprehensive final report by the RCA Laboratories covering several years' work for the U.S. Navy, covers directly or indirectly practically all of the research and development and most of the production design that had been done in its field at the date of publication. It is not, however, just a recitation of work done, but a thorough treatment of the entire specialized subject. The material is excellently planned and written, and avoids unnecessary length by assuming the reader is well acquainted with normal techniques of radio engineering and the ordinary principles of pulse radar and servo mechanisms. Mathematics is largely avoided but is included where necessary to give the serious student a sufficiently complete foundation for further work.

Part I covers principles and techniques, including an especially excellent chapter on the kinematics of aircraft and missile motions involved in elementary fire-control problems. Part II covers single-target and multiple-target FM radar systems, with a very useful chapter on accessory circuits and methods of calibration.

The book is certainly an essential part of every advanced radar engineer's library.

C. A. Priest

Cosmic Radiation

Colston Papers: Vol. I—Symposium promoted by the Colston Society and University of Bristol—Interscience Publishers, Inc., New York. 1949. viii+189 pp. $5.50.

Contained herein are the contributions to the first of a series of annual symposiums, held at the University of Bristol in September, 1948, under the auspices of the Colston Research Society.

The papers, revised by the authors after the discussion, give a clear and excellent presentation of the important postwar advances in the cosmic-ray field, with extensive references to the original literature. The main emphasis is on experimental results and methods (photographic emulsion, cloud chamber, and counter), including sections by such well-known men as Rossi, Powell, Rochester, Bradt, and Janossy, on the primary radiation, star production, light (μ) mesons, heavy (π) mesons, and showers. There is a good theoretical section on meson theory by Heitler, Rosenfeld, and Moller which is descriptive rather than technical and mathematical, and hence understandable to readers without extensive theoretical background.

In most respects the book is timely, since the past year has seen, for the most part, refinements of the included material. Postwar additions to shower theory and the Berkeley work on artificially produced mesons are referred to only briefly, since much of this work postdates the symposium. *Cosmic Radiation* is beautifully printed, and it provides a good way for the reader with some physics background to become acquainted with the recent advances in the understanding of cosmic radiation, particularly the mesonic and primary components.

R. Ehrlich

Fundamentals of Radio-valve Technique

J. Deketh—N. V. Philips' Gloeilampenfabrieken, Eindhoven (Netherlands). 1949. Distrib. in U.S. & Canada by Elsevier Publishing Co., Inc., New York. 557 pp. $5.00.

The title of this book reveals at once that it comes from across the Atlantic, but it is somewhat misleading in that the book contains only a limited amount of information on tube design and manufacture and covers only broadcast receiving tubes. For instance, there is no chapter on glasses, and only one paragraph each is devoted to grid emission and seal electrolysis—two most important factors in tube design. It is thus primarily of use to those not specialized in radio and allied techniques, providing an impression of the construction and functioning of radio valves and their applications in receiving sets.

It is the first volume in a series of seven on electronic valves being published by the Philips Company of the Netherlands. Practically all tubes covered by the text are products of that company, which is true also of the references.

The subject of noise, hum, and microphonics is well covered. To an American reader, the terms "island effect," "Volta effect," "switch effect," and "hail effect" may not sound familiar, but only the names are new.

If you want to present a gift to an engineering friend in Stockholm, Madrid, or Helsinki, here's your chance, as this book is being published in eight languages, as usual "including the Scandinavian."

W. C. White

Soils: Their Physics and Chemistry

A. N. Puri—Reinhold Publishing Corp., New York. 1949. xv+550 pp. $7.00.

The increased scientific interest concerning the many properties of soil in such diverse fields as conservation, hydrology, agriculture, and bacteriology makes this book of timely interest. Written by an outstanding authority in soil science, the book constitutes an important contribution to that important field.

By dividing the subject matter into three major parts—the chemistry, the mechanical analysis, and moisture relationships of the soil—it is possible to quickly locate pertinent data. Of particular interest is the presentation of much experimental data.

Simple, yet complete, descriptions of experimental procedures are employed throughout the text, with original field studies used to illustrate the author's thesis. The book would be more complete if references had been made to the important original publications from which the data were drawn, together with references to important contributions by others.

Although some of the text seems unduly voluminous, the book is apparently directed to the beginner as well as the experienced research worker; and since there are few books of a similar nature on the subject, it is quite possible that this text will be actively used in the clarssoom. It is recommended to anyone desiring to know more about the complex relationships which exist among the soils of the earth.

Vincent J. Schaefer

Electrical Engineers' Handbook: Vol. I—Electric Power (4th Edition)

Edited by Harold Pender & Wm. A. Del Mar—John Wiley & Sons, Inc., New York. 1949. xii+1700 pp. $8.50.

The best judge of the value of a handbook is the man who uses it for his day-by-day reference. Most engineers are quite familiar with the third edition of the Electrical Engineers Handbook, published in 1946. The fourth edition follows the same general pattern but on the whole has been brought up to date and improved to a considerable extent. Probably most users of the third edition would agree that the fourth edition is very much worthwhile.

A broad view of the problems of electric power engineering is given, with ample bibliography for a deeper study into any of the material covered. The material is sufficient to give the broad aspect of electric power engineering not only to the electrical engineer but also to engineers in the associated fields.

Tables of conversion and properties of materials are tailored to the requirements of electric power engineering.

Fred Baumann

Acoustic Measurements

Leo L. Beranek—John Wiley & Sons, Inc., New York. 1949. 914 pp. $7.00.

In any field there is some gap between theory and practice. Nowhere, however, has this gap been more annoyingly in evidence than in acoustics—the reason being, of course, the high degree of complexity in even the simplest of real-life acoustic situations. Such situations do not lend themselves to mathematical treatment without simplifying assumptions which usually distort reality to such an extent that the theorist throws up his hands and calls in the experimenter.

Acoustic Measurements is probably the most determined effort yet made to meet this difficulty head-on. It is a scholarly treatment of a practical subject; basic physical theory is applied to common current problems in architectural acoustics, communication, sound measurement and analysis. There is no clear structural plan in the organization of the 20 chapters, but the internal organization of individual chapters is straight enough. The style is terse and compact, despite the 900 pages.

The result of all this is an invaluable technical treatise, summarizing much of the important recently published research in air acoustics, as well as hitherto unpublished matter. Illustrations and diagrams are plentiful and well chosen. There are many footnotes but no bibliography; the index is less complete than one would wish. Instruments and devices mentioned are not identified directly by the name of the manufacturer.

It is difficult to single out any part of the book for special mention, but one may well call attention to the unusually detailed treatment of the statistics of random noise. One may note, too, that the many descriptions of existing apparatus lead to suggestions for further developments. Clearly then, this book is at once a mine of information and a stimulus to original thinking.

G. E. Henry

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LIBRARY NOTES

ON ARTICLES IN OTHER TECHNICAL JOURNALS

ALLOYS

CHROME MAGNET STEEL. L. H. Seabright. *Iron Age*, Mar. 16, 1950; v. 165, p. 0.

Care in casting, working, and annealing magnet steel is needed for maximum magnetic characteristics and workability. Description of tests showing importance of proper heat treatment of a 3.5-percent chrome steel.

NEW COBALT-BASE ALLOY FOR HIGH-TEMPERATURE SHEET. W. O. Binder and H. R. Spendelow, Jr. *Metal Prog.*, Mar. 1950; v. 57, pp. 321-326.

A superior high-alloy sheet, for use at temperatures up to 1800 F, has been based on 50-percent cobalt, with chromium, nickel, and tungsten.

ELECTRIC CONTROL SYSTEMS

HOW D-C SYNCHROS WORK. Robert A. Gerg and Charles R. Mikolic. *Prod. Engng.*, Mar. 1950; v. 21, p. 137.

Yielding relatively simple solutions to many control problems that are difficult or impossible with a-c synchro systems, the new d-c positioners are also said to compete in performance and cost. Serial.

MICROWAVES OFFER NEW CONTROL FUNCTIONS. W. C. White. *Elec. Mfg.*, Mar. 1950; v. 45, p. 86.

Here are the basic facts for an understanding of microwave characteristics adaptable to control functions.

ELECTRODES

APPLICATION OF MILD-STEEL ELECTRODES. F. R. Strate and R. I. Strough. *Weld. Jour.*, Mar. 1950; v. 29, p. 193.

How the application of welding to code work limits the selection of electrode to that suitable for the specific code.

GRAPHITE ELECTRODES. H. G. MacPherson. *Jour. Metals*, Mar. 1950; v. 188, p. 481.

When an electrode column is pulled rapidly out of an electric steel furnace there results a terrific thermal shock. The degree of this shock is calculated, and measurements are described to determine thermal conductivity, thermal expansion, modulus of elasticity, and strength.

FLUID FLOW

GRAPHICAL, MECHANICAL, AND ELECTRICAL AIDS FOR COMPRESSIBLE FLUID FLOW. H. Poritsky and others. *Jour. App. Mech.*, Mar. 1950; v. 17, p. 37.

Graphical, mechanical, and electrical methods of studying two-dimensional and axially symmetrical irrotational flow of nonviscous compressible fluids are described and examples are given of problems solved by these methods.

STEADY FLOW OF NONVISCOUS ELASTIC FLUIDS IN AXIALLY SYMMETRIC CHANNELS. M. H. Vavra. *Jour. Aero. Sci.*, Mar. 1950; v. 17, p. 149.

An iteration method is described which serves to calculate arbitrary three-dimensional flow fields.

FLUORESCENT LIGHTING

COLOR PREFERENCE STUDIES WITH FLUORESCENT LAMPS. G. B. Buck, II. *Illum. Engng.*, Mar. 1950; v. 45, p. 165.

New spectral reflectance data are presented for representative items including foods, complexions, and various environmental materials.

WHAT OF FLUORESCENT STREET LIGHTING? J. P. Rutherfoord. *Elec. Wld.*, Mar. 13, 1950; v. 133, p. 79.

Summary of progress so far, indicating that fluorescent has promise of reaching practicality for street and highway use.

GAS TURBINES

GAS-TURBINE COMPOUNDING ADDS 550 HP TO ENGINE. *Prod. Engng.*, Feb. 1950; v. 21, p. 92.

Describes the new Turbo-Cyclone compound engine, whose basic structure is a standard 2700-hp radial engine upon which are mounted three exhaust-driven gas turbines.

IMPELLER BLADE DESIGN FOR MAXIMUM STRENGTH WITH MINIMUM WEIGHT. Harold Woodhouse. *Mach. Design*, Feb. 1950; v. 22, p. 111.

Develops a mathematical expression for obtaining the ideal radial profile of a blade to give minimum weight for a selected maximum tensile strength.

GEARS

MANUAL OF GEAR-FINISHING EQUIPMENT. Charles G. Pfeffer. *Am. Mach.*, Mar. 20, 1950; v. 94, p. 105.

A comprehensive review of the latest finishing equipment now available, together with basic information on the use, capacity, and method of operation of each different type.

HEAT TRANSFER

HEAT TRANSFER. William H. McAdams. *Chem. Engng. Prog.*, Mar. 1950; v. 46, p. 121.

The fundamentals of the several types of heat transfer; summarizes recent developments, and outlines needs for further work.

LABORATORY STUDIES ON HEAT FLOW WITHIN A CONCRETE PANEL. C. M. Humphreys and others. *Heat. Piping & Air Cond.*, Apr. 1950; v. 22, p. 109.

Equipment for studying heat flow within concrete panels is described, and results of tests on three panels are reported.

MACHINERY

BRAZING AND WELDING METHODS OF SUBASSEMBLIES. P. H. Brotzman and others. *Metal Prog.*, Feb. 1950; v. 57, p. 213.

Covers silver, copper, and aluminum brazing and inert-arc welding of subassemblies.

CO-ORDINATED CONTROL OF CARBIDES ESSENTIAL TO ECONOMICAL USE OF MULTI-PURPOSE MACHINES. J. Smith. *Tool Engr.*, Feb. 1950; v. 24, p. 20.

Describes the operation of the Carboloy Company's co-ordinated carbide-control program.

PLASTICS

PLASTICS PIPES INVADE NEW MARKETS. *Modern Plastics*, Mar. 1950; v. 27, p. 69.

Chemical resistance, light weight, and ease of installation are given among the reasons why plastics are replacing conventional materials in many industrial piping applications.

SPECIAL MOLDS FOR PLASTIC PARTS. John J. Johnescu. *Mach.*, Feb. 1950; v. 56, p. 168.

Examples of plastic molds of advanced design, including double-deck molds and plunger type transfer molds.

SOUND RECORDING AND REPRODUCTION

INCREASED NOISE REDUCTION BY DELAY NETWORKS. J. R. Whitney and J. W. Thatcher. *Soc. Mot. Pict. & Telev. Engrs. Jour.*, Mar. 1950; v. 54, pp. 295-302.

Describes a new method of obtaining increased signal-to-noise ratio in optical sound-film recording.

MAGNETIC RECORDING SYSTEMS IN PRODUCT DESIGN. Alex. E. Javitz. *Elec. Mfg.*, Feb. 1950; v. 45, p. 74.

A review of the major elements in these systems, plus some design case histories.

PULSE PACKING IN MAGNETIC RECORDING WIRE. Irvin L. Cooter. *Nat. Bur. Stds. Jour. Res.*, Feb. 1950; v. 44, p. 163 (RP No. 2067).

An oscillographic method is described for determining the relative pulse packing of different types of magnetic recording wire used for pulse storage.

TITANIUM

TERNARY ALLOYS OF TITANIUM. C. M. Craighead and others. *Jour. Metals*, Mar. 1950; v. 188, p. 514 (Metals Trans.)

The results of a preliminary study of 113 ternary titanium-base alloys are described.

TITANIUM SYMPOSIUM. O. C. Ralston and F. J. Cservenyak. *Ind. & Engng. Chem.*, Feb. 1950; v. 42, p. 214.

Eleven articles on the uses, properties, and alloys of titanium.

WELDING

COLD PRESSURE WELDING OF NONFERROUS METALS. *Prod. Engng. & Man.*, Mar. 1950; v. 25, p. 63.

Recent developments which indicate an extended use of this new welding process.

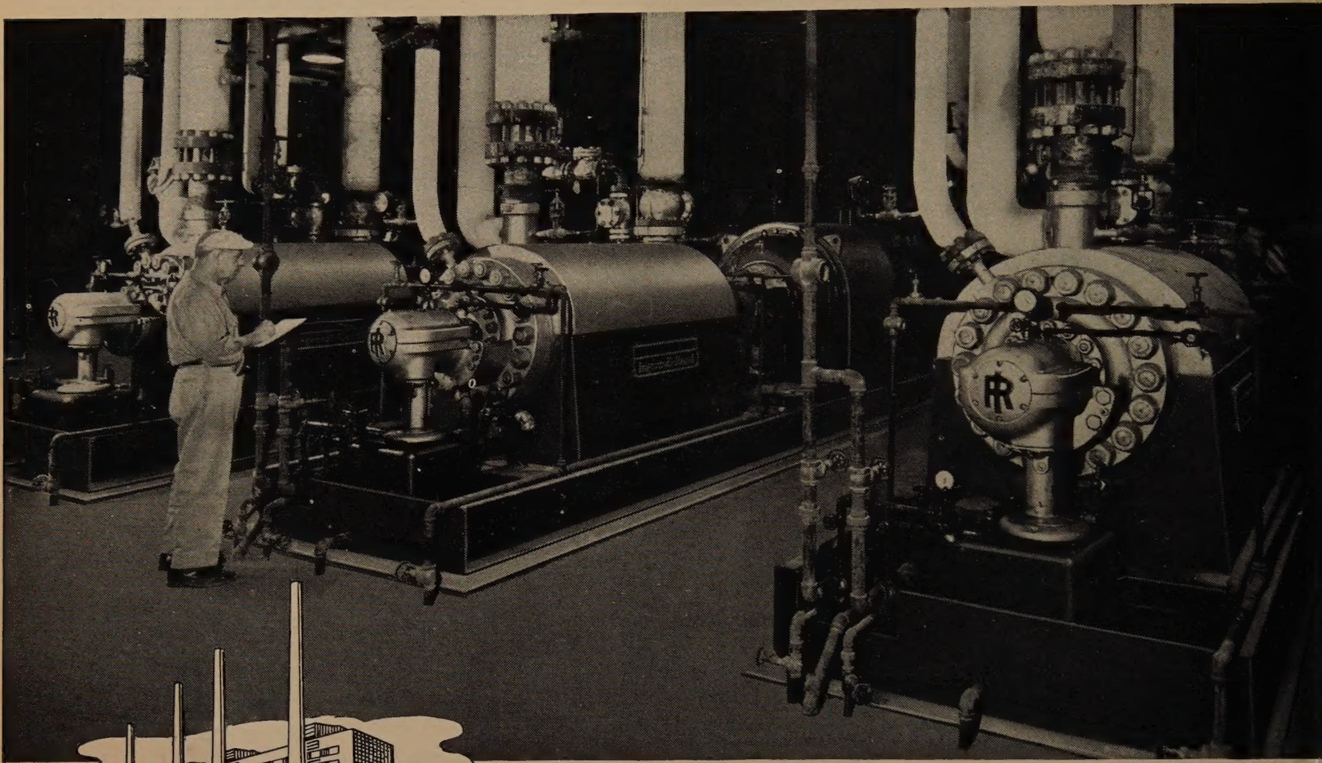
DIRECT EXPLOSION OF WELDED JOINTS. G. S. Mikhalapov. *Weld. Jour.*, Mar. 1950; v. 29, p. 109s.

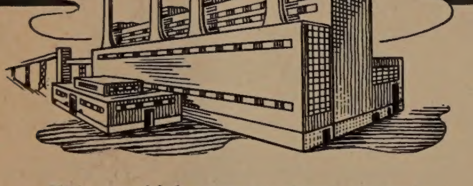
A new technique for determining triaxia sensitivity of steel plates and weldments is described.

STABILITY TESTS OF WELDING MACHINES. Charles L. Volff. *Weld. Jour.*, Apr. 1950; v. 29, p. 290.

French arc-welding specifications are reviewed, and the principle of stability tests and methods used and their significance described.

NEW PHILIP SPORN STATION TO INSTALL 24,000 HP OF I-R BOILER-FEED PUMPS





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